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ESTABLISHMENT OF A CUTTING FLUID CONTROL SYSTEM (PHASE II)

G.A. LIEBERMAN

MAY 1982

U.S. ARMY

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TECHNICAL REPORT

TRW, INC.

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Phase II results are presented for the program entitled "Establishment of a Cutting Fluid Control System." The Phase II objectives were to conduct a systematic evaluation of available cutting fluid products, refine the Phase I preliminary RIA manufacturing process severity index and preliminary cutting fluid application matrix. The study showed the majority of observed machining operations involve milling, turning, grinding and boring procedures on 4100 series steels. A severity index was finalized which ranked all these processes relative to machining difficulty with respect to manufacturing parameters, tool

design, workpiece hardness, and specific machining process. Commercially available cutting fluids were also categorized according to composition and manufacturer's recommendations. A total of eighty-four fluids were recommended for testing by twenty-three cutting fluid manufacturers. Fluids were subjected to initial screening tests involving residue, rust and bacteria growth with selected fluids then employed in machining tests. The latter tests employed specially instrumented machine tools which provided force, power consumption, and tool wear data.

Results are presented which indicate fluid performance levels are not necessarily related strictly to overall product formulations and that milling and turning require significantly different fluid properties. Data are also presented which suggest that only a very limited number of fluid types may be required for plant-wide application at Rock Island Arsenal. Methodologies are defined for establishing a quantitative index describing the relative severity of any given metal removal operation in relation to the fluid properties required for optimum performance on the machine. A cutting fluid application matrix is presented describing the generic cutting fluid properties required for the various severity machining operations performed at the Arsenal. Initial recommendations are also presented outlining the design features for a closed-loop fluid reprocessing system.

FOREWORD

This report was prepared by Mr. G. A. Lieberman, Machining Technology, TRW, Inc., Cleveland, OH, in compliance with Contract No. DAAA08-80-C-0033. Program management was provided by Mr. J. C. Lawrence, Section Manager and Dr. C. F. Barth, Department Manager. Technical support was provided by J. M. Gorse, C. M. Imler, and R. A. Whittington. The TRW Internal Report No. ER-8156-F has been assigned for this report.

This work was under the direction of the Engineering Directorate, Rock Island Arsenal, Rock Island, IL, with Mr. R. E. Johnson as Project Engineer.

This project was authorized as part of the Manufacturing Methods and Technology Program and was administered by the U. S. Army Industrial Base Engineering Activity.

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READERS NOTE:

It should be emphasized that the primary program objective has been to develop a cutting fluid control system. One of the tasks was to evaluate commercially available products such that performance characteristics based on generic fluid types could be established relative to requirements for Rock Island Arsenal. Mention of specific products must not be construed as an endorsement of any kind, but as an example of suitable products representative of a particular generic fluid type.

1.0 INTRODUCTION

For the past two years, TRW Materials Technology has been actively researching the state-of-the-art of cutting fluid application technology for the Rock Island Arsenal (RIA). The objective of this program is to establish and organize cutting fluid selection and control systems based upon performance data which will improve productivity and reduce the costs of manufacturing in the machining area of the Arsenal. The program has been organized to take place over three years with incremental annual funding.

Phase I, or the effort for the first year, was designated for data gathering and analysis of the manufacturing processes at the Arsenal. A survey of the RIA manufacturing facility was conducted to be used as a data base to develop laboratory test simulations and construct a preliminary machining severity index. The preliminary machining severity would later be refined and used to aid the Arsenal in specifying a cutting fluid for a particular application. Provisions will be made to allow the Arsenal to update the severity index with future machining operations. The Phase I program effort was published under RIA Technical Report No. EN-81-02, Establishment of a Cutting Fluid Control System (Phase I) by G. A. Lieberman.

Phase II, or second year program effort, was a continuation and refinement of Phase I. The preliminary severity index was refined and additional cutting fluid tests were performed. These tests were used to finalize the cutting fluid application matrix and develop a cost benefit analysis.

Phase III of the program will be the implementation phase. The highlight of this phase will be the demonstration of selected cutting fluids on actual production equipment and parts in the Arsenal. Instruction will be given in how to continuously use the cutting fluid selection process, machining severity index, and cutting fluid application matrix. Also, recommendations for a complete cutting fluid control system for the Arsenal will be presented.

This report describes the work accomplished in Phase II of this program.

2.0 BACKGROUND AND TECHNICAL APPROACH

The extensive background that TRW Materials Technology has developed over the past decade was presented in depth in the Phase I report, Establishment of a Cutting Fluid Control System (Phase I), by G. A. Lieberman. This section outlines the technical approach employed for Phase II of Establishment of a Cutting Fluid Control System.

2.1 Technical Approach

The objective of Phase II of the Rock Island Arsenal's "Studies to Establish a Cutting Fluid Control System" was to further refine the existing preliminary Cutting Fluid Application Matrix. This matrix is designed to provide the RIA with the ability to select an adequate cutting fluid for existing and future manufacturing processes. In order to accomplish this, two basic steps were taken: data collection and the test design and evaluation. The following subsections will describe these steps.

2.1.1 Data Collection

In order to develop a cutting fluid application matrix, data was gathered from the RIA. Each manufacturing process performed at the Arsenal was analyzed and when possible tool samples were collected. Then a severity index was developed to classify the different types of manufacturing processes observed and to relate them to the other manufacturing processes performed throughout the Arsenal.

Once these data were gathered, a survey of the commercially available cutting fluids was initiated. As many cutting fluid manufacturers were contacted as feasible and asked to recommend products for RIA. They were required to complete a detailed questionnaire for each neat oil product and water soluble product recommended. A computer program was developed to analyze the information supplied by the cutting fluid manufacturer. Concurrently, preliminary screening tests were performed on test fluids submitted by the cutting fluid manufacturers. These preliminary tests included a rust test, a test for resistance to RIA bacteria, and a residue test. These tests were utilized to eliminate products exhibiting fundamentally undesirable properties. Also, telephone contact was made with all the participating fluid manufacturers to gain insight into the chemical and physical makeup of their products. As many interviews as possible were held with the chief chemists of the fluid manufacturers. This provided information necessary to learn the chemistry of cutting fluids passing the initial screening tests and how best to apply them.

2.1.2 Test Design and Evaluation

After investigating the area of cutting fluid application and the severity of RIA machining operations, initial test fluids were selected for evaluation. Initially, these fluids were grouped into three categories using manufacturer supplied data: heavy duty, medium duty and light duty. Also, each category was

subdivided into generic subgroups. Each manufacturing process studied was tested with three generic types of cutting fluids, viz., emulsions, semi-synthetics, and full synthetics of the category applicable to that machining process.

An emulsion or soluble oil is a cutting fluid containing approximately forty to sixty percent oil. Emulsions are generally opaque and have the ability to mix in both water and oils. Semi-synthetics typically contain from five to twenty percent oil and are translucent. As with emulsions they have the ability to mix with water or dissolve oil. Full synthetics contain no natural oil and most full synthetics are immiscible with oils. They are generally transparent due to the fact full synthetics are true solutions.

The selection process for the application matrix involved design and performance of a series of metal removal tests. These tests considered all major manufacturing processes currently in use at RIA and utilized the same range of metal removal parameters. The candidate fluid products were evaluated by the following processes, in each case, the variables controlled or monitored are indicated.

1. Grinding:

   a. Wheel Grade
   b. Wheel Speed
   c. Table Speed
   d. Cross Feed
   e. Total Depth of Cut
   f. Infeed
   g. Wheel Dressing Method
   h. Material

2. Turning and Boring:

   a. Tooling
   b. SFM
   c. Feed
   d. Doc
   e. Material

3. Milling:

   a. Tooling
   b. SFM
   c. Chipload
   d. Feed
   e. Cutter Diam.
   f. Doc
   g. Material

4. Drilling:

   a. Tooling
   b. SFM
   c. Feed
   d. Hole Geometry (Diameter, Depth)
   e. Material

Force data was collected during metal removal tests using a Honeywell 1858 Visicorder which utilizes light sensitive paper and fiber optics. This instrument has a much faster response time than a conventional chart recorder. The additional response time allowed for more representative data to be collected. Force information was supplied to the Visicorder by Kristal Instruments piezoelctric machining dynamometers. Piezoelectric dynamometers provided a higher frequency response capability than conventional strain gages, thus supplying additional information for data analysis. Instantaneous horsepower consumption was measured with a Valenite wattmeter connected to the spindle motor windings. Velocity measurements were taken using an LVT (Linear Velocity Transducer).

The following factors were considered in cutting fluid evaluation:

1) Dynamometer forces

2) Power consumed during machining

3) Tool wear

4) SEM evaluation of the tool

Fluids that showed lower forces, minimum power consumption and the least tool wear were evaluated as being technically superior. Additional considerations included in the selection process included installation costs, operator acceptance, maintenance and disposal requirements.

3.0 RESULTS AND DISCUSSION

The Phase II program results are discussed in this section. Due to the program complexity, discussion of these results has been subdivided into a number of individual elements. These elements fall into four basic categories: development of RIA's application matrix, commercially available cutting fluids, test results, and development of the RIA application matrix with cost benefit study. Each element describes an individual aspect of the overall program and they have been organized to follow sequentially in a logical manner. Continuity of the discussion for each manufacturing process is therefore maintained and the accompanying analysis can be more specialized for each case treated. Further, each element can be examined on an individual basis without detraction from the report as a whole.

This section will begin by reviewing the highlights of the in-depth analysis of the current RIA manufacturing process conducted during Phase I. Then present the further refined RIA severity index. The results of the cutting fluid screening tests will then be reviewed. In addition, the criteria of test fluid selection will be discussed. Following these subsections, other subsections will therefore treat milling and turning cutting fluid testing. The final subsection will present a cutting fluid application matrix and a cost benefit study.

3.1 RIA Severity Index

The objective of this portion of the program is to establish a quantitative methodology of ranking metal removal operations. The ranking system is intended to group these operations relative to their severity such that specific cutting fluid properties can be established for each of these groups. The work accomplished in the Phase I program effort has permitted establishment of a preliminary system for assignment of severity indices to individual operations within process classes, such as turning, milling, and grinding, and to weigh these indices for interclass comparisons. Phase II has further refined this into a completed severity index.

3.1.1 Background

During the Phase I program activity, a series of surveys were made at RIA to develop a comprehensive data base describing manufacturing operations being conducted at the Arsenal. This was a very important phase of the program since the severity index was developed from this data base. Also, the data gathered would be used as guides to structure the machining tests as well as establishment of a basis for selecting trial cutting fluids. Great care was taken in order to select representative data. The parts and operations were chosen after many discussions with Rock Island Arsenal's general management, and line foremen from first and second shifts. A specially designed data sheet was developed that would insure that all the pertinent data about any given machining operation would be obtained. An example of this sheet, used to describe a turning operation, may be viewed in Figure 3.1-1.

This sheet contains all the information necessary to develop a machining severity index, such as the feed, speeds and depth of cut of the machining operation. Such

PART NUMBER: 12007623

OPERATION: Turn OD   Severity : High Med Low

MATERIAL: 4130 Steel CO Tube   Hardness: Rc 25 to Rc 30

EQUIPMENT: #823861 American Tracer   LOT QUANT: 196 Min. -- Max.

CURRENT FLUID: Type: Water   Name: Trim Sol   Mfr. Master Chemical

Concentration: 30 : 1

MACHINING DATA:

CONFIGURATION: Cylinder 40.5 inches long, 3.625 inches diameter

	Min. Rough	Max. Finish
SFM:	256	302
DIAM.WORKPIECE:	3.625	
RPM:	270	318
FEED RATE:	0.0173	0.0173
DEPTH OF CUT ROUGH:	0.250	
DEPTH OF CUT FINISH:		0.0125
H.P.:	10	

TOOLING DATA:

GEOMETRY: Carbide Insert Triangle 516 TNMG 543E

NO. OF CUTTING EDGES: 6   CHIP BREAKER ON TOOL: YES ✓ NO ___

MFR: Carboloy   NEW TOOL COST: $7.11

CURRENT LIFE: Min: 5 pcs/edge   Max. ___

TOOL CHANGE TIME: 1 min.   OPERATOR COST: $43.72

NEED SETUP MAN: No ✓ Yes ___   SETUP MAN: $ DNA /Hr.

HOW FLUID IS APPLIED TO PART: Applied to top of part and tool through a nozzle that moves with cutting tool. Adequate fluid flow was observed.

4.7.80

Figure 3.1-1. Cutting Fluid Test Data Sheet for Turning.

information aids in determining the heat buildup, the type of chip loading, and forces the cutting tool may be experiencing. The hardness of the workpiece was also examined. The hardness level is important in determining what cutting temperature the cutting tool may experience as well as helping to evaluate the cutting tool geometry and required surface speed. Part of the form is devoted to tooling and tool geometry.

During the Phase I visits, 76 individual machining operations were observed. These operations had been performed on 24 different parts. Most of the observations were of milling, turning, grinding and drilling operations. Data were also obtained which showed that these four basic operations represent 91% of total monthly operating hours, Table 3.1-1. The specific machining operations and parts studied are displayed in Table 3.1-2. Over 95% of these parts are manufactured from 4100 series steel. Therefore, these results indicate that the primary emphasis of the severity index and cutting fluid analysis be focused on the manufacturing of parts with 4100 series materials. Final fluid selections will include considerations for efficient machining of non-ferrous alloys.

Such a course of action would maximize Rock Island Arsenal's rate of return on its cutting fluid contract investment. This position may be emphasized by the following illustration. Suppose that a special cutting fluid could increase tool life for non-ferrous machining by 100%. The cost savings generated by this new fluid would only be a fractional percentage of the potential cost savings that could be realized by achievement of a 5% increase in life for tools machining ferrous materials by using products tailored primarily for the 4100 series alloys.

The data gathered at RIA are being used to define the severity of each operation observed. The severity analysis will then be used to develop the exact parameters which will be used to simulate the observed machining operations at Machining Technology's Laboratory. The objective of this analysis will be to develop a cutting fluid and machining severity index that will match cutting fluid properties with machining process severity index that will match cutting fluid properties with machining characteristics. This requires that a quantitative index be established which defines the relative severity of machining operations at the Arsenal. The index combines cutting parameters, tool design, and material properties such that the various operations can be ranked. Development of an index has been accomplished and a discussion of the formulation rationale is presented in section 3.1.2.

3.1.2 Basic Data

The data collection sheets, such as shown previously in Figure 3.1-1, that were completed during the 28 April 1980 visit were consolidated into a summary form. These data appear in Tables 3.1-3 through 3.1-9 for each class of machining operations. In each case, the columns across the top of the data tabulation refer to key parameters associated with the various process classes.

After studying the process data analysis sheets, some machining operations' severity is quite apparent. For example, the turning operation in Table 3.1-3 for part number 8382446, which has 848 SFM, 0.140 inch depth of cut, 0.026 inch/revolution feed rate, and a metal removal rate (MRR) of 37 cubic inches per minute, seems to be severe, especially compared to part number 8449036 whose SFM = 781, depth of cut = 0.020 inch, feed rate = 0.026 inch/revolution and MMR = 4.9.

TABLE 3.1-1

TOTAL MONTHLY HOURS OF THE BASIC MACHINING OPERATIONS PERFORMED AT ROCK ISLAND

Basic Operation	Hours Operation Per Month	% of Total Hours
Turning & Boring	40,000	31
Milling	37,000	29
Grinding	30,400	23
Drilling	10,100	8
Sawing	6,500	5
Planing	3,000	2
Broaching	3,000	2
Total	130,000	100

TABLE 3.1-2

Summary of Data Gathered at RIA

Operation Type	Part Number	Number of Different Operations Observed	Material
N/C Turning	8449036	30	4100
N/C Turning	8382446	1	4100
N/C Turning	10895646	1	4100
Turning	10891793	1	4100
Turning	10956584	1	4100
Turning	12007666	1	4100
Turning	12007623	1	4100
Turning	8449307	2	4100
N/C Milling	8449309	10	4100
Milling	7133213	1	Stainless
Milling	7793063	1	4100
Milling	7791379	1	4100
Milling	6532032	1	4100
Milling	10884271	1	4100
Tapping	8449309	4	4100
Drilling	8449309	8	4100
Boring	5507239	1	4100
Boring	8449307	2	4100
Boring	6508894	1	4100
Broaching	7793146	1	8169
Broaching	10892198	1	4100
Grinding	10901204	1	4100
Grinding	6538758	1	4100
Grinding	6538757	1	4100
Grinding	12007805	1	4100
Grinding	12012329	1	4100

TABLE 3.1-3

RIA Manufacturing Data Analysis Sheet for Turning

Part No.	Operation	SFM	Depth of Cut (in.)	Feed Rate	Hardness	OTW	MRR
8449036	N/C Face	422	0.005	0.013	BHN 170-248	CH	0.3
8449036	N/C Rough Turn OD	781	0.140	0.026	BHN 170-248	CR	34.1
8449036	N/C Finish Turn OD	781	0.020	0.026	BHN 170-248	CR	4.9
10891793	Turn OD with Ceramic	413	0.150	0.014	R_c25-30	CH	10.4
10956584	Turn OD with Ceramic	413	0.150	0.014	R_c29-36	CH	10.4
12007666	Turn OD	372	0.100	0.015	R_c33-35	-	6.7
12007623	Turn OD	256	0.250	0.017	R_c25-30	G	13.1
8449307	Turn OD	423	0.060	0.015	R_c26-32	CH CR	4.6
8382446	N/C Turn OD	848	0.140	0.026	R_c26-32	-	37.0
8382446	N/C Turn OD	761	0.140	0.026	R_c26-32	-	32.2
10895646	N/C Turn OD	411	0.140	0.018	R_c20-25	-	12.4

Key: SFM = Workpiece velocity, surface feet per minute.
Depth of Cut = Tool engagement normal to feed direction, inches.
Feed Rate = Tool advancement rate, inches per revolution.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.

TABLE 3.1-4

RIA Manufacturing Process Data Analysis Sheet for Boring

Part No.	Operation	SFM	Depth of Cut	Feed Rate	Hardness	OTW	MRR
5507239	Bore ID	197	0.125	0.013	NHS	G	3.8
8449307	Bore ID	237	0.125	0.015	R_c26-32	-	5.3
8449307	Bore ID	294	0.128	0.015	R_c26-32	-	6.6
8449307	Bore ID	316	0.060	0.015	R_c26-32	-	3.4
6508898	Bore ID	221	0.187	0.012	BHN 242-248	CH	6.0

Key: See Table 3.1-3.

TABLE 3.1-5

RIA Manufacturing Process Data Analysis Sheet for Milling

Part No.	Operation	SFM	Feed Tooth	MRR	Feed Rate	Hardness	OTW
8449309	Dry Face N/C Milling	314	0.002	60.3	4-8	NHS	CH
10884271	Dry Face Milling	702	0.003	315.9	12.5	R_c25-30	
8447309	Slot Milling N/C	314	0.005 0.008	150	3-5	NHS	
8447309	Side Milling N/C	398	0.004 0.007	267	5-8	NHS	CH
8447309	Side Milling N/C	314	0.0035 0.0026	53	3-4	NHS	CH
8447309	Whisper Cut Face Milling N/C	629	0.002	121	8	NHS	CH
8447309	N/C End Mill	60	0.0015	2	1.5	NHS	
8447309	N/C End Mill	334	0.001	40	2.0	NHS	
7133213	End Mill	62.4	0.008	12	2	NHS	
6532032	End Mill	32	0.004	3	2	NHS	CH
8449309	End Mill N/C	63	0.0016	4	3	NHS	
8449309	Bore N/C End Mill	57	0.003	6	3	NHS	
8449309	Bore N/C End Mill	64	0.001	5	6	NHS	
7793063	Face Mill Dry	650	0.002	119	7.625	R_c31-38	CH
7791379	Peripheral Mill Conventional	47	0.005 0.0047	7	2.625 2.125	R_c42-46	

Key: SFM = Tool velocity, surface feet per minute.
Feed per Tooth = Amount of material each tooth removes in inches.
Feed Rate = Tool advancement rate, inches per minute.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.

TABLE 3.1-6

RIA Manufacturing Process Data Analysis Sheet for Drilling

Part No.	Operation	SFM	Depth of Hole	Feed Rate	Hardness	L/D
8447309	Spot Drill	157	0.525	0.0025	NHS	DNA
8447309	Drill	59	0.863	0.0075	NHS	1.3
8447309	Drill	59	1.5	0.0075	NHS	2.7
8447309	Drill	52	0.50	0.0067	NHS	1.1
8447309	Drill	51	0.5	0.004	NHS	2.6
8447309	Drill	55	0.63	0.0096	NHS	0.8
8447309	Drill	41	1.0	0.003	NHS	6.4
8449309	Core Drill	70	3.5	0.01	NHS	DNA

Key: SFM = Tool velocity, surface feet per minute.
Feed Rate = Tool advancement rate in inches per revolution.
L/D = Length of hole/diameter of hole.
DNA = Does not apply.

TABLE 3.1-7

RIA Manufacturing Process Data Analysis Sheet for Tapping

Part No.	Operation	Hole Type	SFM	Depth of Hole	Feed Rate	Hardness
8449309	1/2-20 UNF Tap	B	26.2	1.00	10	NHS
8449309	1/4-20-UNC-2B Tap	B	13.0	0.5	10	NHS
8449309	1-8 UNC-2B Tap	B	21.0	2.62	10	NHS
8449309	10-32 UNF-2B Tap	T	16.0	1.0	10	NHS

Key: SFM = Tool velocity, surface feet per minute.
Feed Rate = Tool advancement rate, inches per minute.
Hole Type = B = Blind Hole, T = through hole.
NHS = No hardness specified.

TABLE 3.1-8

RIA Manufacturing Process Data Analysis Sheet for Grinding

Part No.	Operation	Material	SFM	Infeed	Work Speed	Crossfeed	Hardness
10901204	OD Cylindrical Grind	4140	4200 (new wheel)	0.001 0.0005	50	1 in/rev	BHN 213/248
6538758 or 6538757	Surface Grind	4140	6021 (new wheel)	0.001 0.0005	35 35	0.200/pass 0.200/pass	NHS NHS
12007805	Surface Grind	4140	6021 (new wheel)	0.0005 0.00025	60 60	0.130/pass 0.130/pass	R_c30/35 R_c30/35
12012329	Cylindrical Grinder	Al-Br Stellite	6283 (new wheel)	0.001 0.0002	25 25	1.6 in/rev	NHS
7793144	OD Cylindrical Grind	Stellite	6600 (new wheel)	0.0001 0.00025	2.5	0.009 in/rev	NHS

Note: All crossfeeds are continuous and manually variable.

Key: SFM = Wheel velocity, surface feet per minute.
Infeed = Amount the grinding wheel moves radially per pass, inches.
Work Speed = The rate the workpiece moves past the grinding wheel, ft/min.
Crossfeed = Amount the grinding wheel moves axially per pass, inches.
NHS = No hardness specified.

TABLE 3.1-9

RIA Manufacturing Process Data Analysis Sheet for Broaching

Part No.	Operation	Material	SFM	Length of Cut	Feed Rate	Hardness	OTW
7793146	Broaching	8169	10	2.5	0.0005	33-36 R_c	G

Key: OTW = Observed tool wear mode.
SFM = Tool velocity, surface feet per minute.
Feedrate = Tool advancement rate, inches per minute.
G = Good.

This example shows how readily two cases of one type of machining can be compared to one another or ranked. Part Number 8382446 is the most severe operation and would receive the highest severity ranking value, and part number 8449036 would receive the lowest rank severity number. However, the goal is not to compare operations within a particular basic machining operation but to compare all the machining operations within RIA. The overall goal will be to use this machining comparison method and combine it with a similar comparison method which is being developed concurrently for cutting fluids. The end result will be a chart that will permit matching a particular machining operation to a cutting fluid at a specific concentration level.

3.1.3 Severity Index Considerations

In order to achieve this goal, an overall severity index must be developed for RIA that will accomplish the following: define severity, be uncomplicated to calculate, and accurately describe RIA requirements.

Severity of a machining operation is usually considered to be a function of the level of difficulty associated with one or a combination of the parameters which describe it. For example, a turning operation's basic parameters are the speed, feed and depth of cut. In all the parameters, the higher the value the more difficult the operation. Also, each parameter must be compared to one another. In the case of turning, increasing the speed produces a more severe operation than increasing the feed; and increasing the feed produces a more severe operation than does increasing the depth of cut. These are the types of considerations taken in the development of the overall severity index.

The purpose of the severity analysis is twofold, first to establish the relative severity within a basic machining operation; secondly, to develop an overall severity index that will be used to compare all of the basic machining operations performed throughout Rock Island Arsenal. The development of the overall severity index, the index that can be related to all the basic machine operations, requires performing three separate tasks. These tasks are ranking the severity levels of the process parameters, developing a consistent scaling technique within these ranks, and extending the ranking to permit comparisons between different processes. The rationale followed for each of these tasks are described individually as follows:

1. Rank the Severity of the Critical Machining Process Variables

Each machining operation has process variables such as speed, feed, depth of cut, etc. These components are ranked on an interval scale from one to three, three being the most severe and one being the least. For example, below is how boring cutting speeds were ranked.

Rank	SFM
3	250 and above
2	100-249
1	0-99

All of the different observations of the basic machining operations being studied can then be ranked in this manner.

2. Develop a Scaling Technique to Define the Most Severe Operations of the Basic Machining Operation Being Evaluated

Establishing a quantitative ranking taking into account all the process variables whose rank was established in task one requires the development of a special technique. First, this technique involves assigning a coefficient of relative importance or weighting factors to each of the process variables rankings defined in Task 1. Second, the summation of the products of the weighting factors times their related rank then provides a number representing the relative severity of the machine operation or observation in question. This logic is then applied to all of the observations of the basic machining operations being evaluated. The result is a representative ranking of the observations of the machining operations being studied. This ranking has been defined as the basic operation severity rank. The weighting factors must be chosen in a manner which will develop a representative spread of the severity of the operation. For example, the operation severity rank will be calculated for boring. First the ranking of each of the basic machining parameters for all the different parts observed as in Task 1 must be accomplished. This is displayed in Table 3.1-10. Next, weighting factors must be developed to take into account the relationship between SFM, feed rate, depth of cut, hardness and metal removal rate (MRR). Past experience has shown that increasing the SFM creates a more severe operation than an increase in feedrate. An increase in feedrate produces a more difficult operation than an increase in depth of cut. Material hardness also has a major influence on machinability. Three ranges of hardness can be established to rank material machinability. Workpieces below R_c28 are readily machined although the chips tend to be stringy and difficult to break. The range between R_c28 and R_c36 represents moderately difficult to machine steels. Alloys heat treated to hardnesses above R_c36 rapidly are more difficult to machine.

All of these considerations were taken into account in the development of the weighting factors displayed in Table 3.1-11 for the boring operation. Lastly, the summation of the products of the weighting factors with their associated rank number is calculated to form the basic operation severity rank. This operation is displayed below in detail for part number 5507239.

$$(R_{Speed} = 2)(WF_{Speed} = 3) + (R_{Doc} = 2)(WR_{Doc} = 1)$$

$$+ (R_{Feed} = 2)(WF_{Feed} = 2) + (R_{Hardness} = 0)(WF_{Hardness} = 100)$$

$$+ (MRR = 3.8)(WF_{MRR} = 17) = 76.6 = \text{Basic Operation Severity Rank}$$

Key: R = Rank
WF = Weighting Factor
Doc = Depth of Cut

TABLE 3.1-10

The Ranking of the Boring Machining Parameters

SFM	Depth of Cut(in.)	Feed Rate (In/Rev)	Hardness	MRR	OTW	Operation	Part No.
197 SFM Rank=2	0.125 Rank=2	0.013 Rank=2	NHS Rank=0	3.8	G	Bore ID	5507239
237 SFM Rank=2	0.125 Rank=2	0.015 Rank=3	R_c 26-32 Rank=0	5.3	-	Bore ID	8449307
294 SFM Rank=3	0.125 Rank=2	0.015 Rank=3	R_c 26-32 Rank=0	6.6	-	Bore ID	8449307
316 SFM Rank=3	0.060 Rank=1	0.015 Rank=3	R_c 26-32 Rank=0	3.4	-	Bore ID	8449307
221 SFM Rank=2	0.187 Rank=3	0.012 Rank=2	BHN 242 248 Rank=0	6.0	CH	Bore ID	6508898

Key: See Table 3.1-3

TABLE 3.1-11

Weighting Factors for Boring

Machining Parameter	Weighting Factor
SFM	3
Depth of Cut	1
Feed Rate	2
Hardness	100
MRR	17

These calculations are continued for all the boring operation in Table 3.1-12.

3. Extrapolate the Basic Operation Severity Rank to an Overall Severity Index

The final step is to establish an index that will be used to compare the currently studied basic machining operations to all the machining operations within Rock Island Arsenal. Again, a one to three interval scale has been utilized. The highest value of the basic operation severity rank is given an overall severity index rank of three. The lowest is given an overall severity index of one. The previously discussed case of the boring was handled in a similar manner. All the values above 100 were given an overall severity ranking of three. All the values above 50 were given a two. Note, in this case, none of the values qualify for an overall severity rank of one.

3.1.4 Turning and Boring

The turning and boring operations may be divided into two basic groups; N/C (numerical control) and conventional. N/C turning contained the most severe operations. This was due to the high surface speed at which the equipment was operated, typically, 700 to 800 SFM. Also, the N/C equipment had larger motors and heavier frames that allowed for an increased depth of cut.

In general, most of the operations observed were run above Machinability Data Handbook standards. This was due to the excellent knowledge of the area foremen and the individual machine operators of how to fully utilize carbide cutting tools and to properly apply cutting fluids. The material hardness was characteristically below the R_c 30 range. Most of the depths of cuts ranged from 0.100-0.250 inch. Typically, the feed rates ranged from 0.013 inch/revolution to 0.026 inch/revolution.

Each turning and boring operation was ranked for its severity in cutting speed, depth of cut, feed rate and hardness through the use of a one to three interval scale, three being the most severe and one being the least severe. Also, each turning and boring operation's metal removal rate was calculated and the mode of the observed tool wear was specified. The overall severity ranking was attributed to the combination of all these factors.

Establishment of a quantitative severity index required combining these five factors (tool wear mode was not used) in a logical manner. A weighting technique was developed which involved assigning a coefficient of relative importance to each of the five factors. Summation of the five products then provides a number representing the relative severity of the various RIA turning and boring operations. This number (the basic operation severity rank) was then converted back to a one to three interval scale which will be used to compare turning and boring to all the other machining operations. This last interval scale is called the overall severity index. The procedure is illustrated in Table 3.1-13 for turning and Table 3.1-14 for boring.

3.1.5 Drilling and Tapping

It was apparent from the analysis sheets that all drilling and tapping operations were conducted at common parameters. Most of the holes had aspect ratios in the 2-3 range with one exception. All tapping was performed at the same rates; hence, it was not necessary to develop individual indices, but a single value can be developed to describe the operations as they are currently performed.

TABLE 3.1-12

Sample Calculations for the Development of the Basic Operation Severity Index for Boring

Part No.	Weighting Factors Times Their Related Ranks					Basic Operation Severity Rank
	(SFM)	(Depth of Cut)	(Feed Rate)	(Hardness)	(MRR)	
5507239	[(R=2)x3] +	[(R=2)x1] +	[(R=2)x2] +	[(R=0)x100] +	(3.8x17)	= 76.6
8449307	[(R=2)x3] +	[(R=2)x1] +	[(R=3)x2] +	[(R=0)x100] +	(5.3x17)	= 104.1
8449307	[(R=3)x3] +	[(R=2)x1] +	[(R=3)x2] +	[(R=0)x100] +	(6.6x17)	= 129.2
8449307	[(R=3)x3] +	[(R=1)x1] +	[(R=3)x2] +	[(R=0)x100] +	(3.4x17)	= 73.8
6508898	[(R=2)x3] +	[(R=3)x1] +	[(R=2)x2] +	[(R=0)x100] +	(6.0x17)	= 115.0

From the above presentation it can be noted that the operation with the 129.2 severity rank is the most severe operation and the operation with the 73.8 severity rank the least.

TABLE 3.1-13

Summary Table for Turning Severity Index Determination

Weighting Factors	3	1	2	100	6				
Overall Severity Index	SFM	Depth of Cut	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
1	422 Rank=2	0.005 Rank=1	0.013 Rank=2	170-BHN 248 Rank=0	0.3	12.8	CH	NC Facing	8449036
3	781 Rank=3	0.140 Rank=2	0.026 Rank=3	170-BHN 248 Rank=0	34.1	221.6	CR	N/C Rough Turn OD	8449036
1	781 Rank=3	0.020 Rank=1	0.026 Rank=3	170-BHN 248 Rank=0	4.9	45.4	CR	N/C Finish Turn OD	8449036
2	413 Rank=2	0.150 Rank=2	0.014 Rank=2	R_c 25-30 Rank=0	10.4	74.4	CH	Turn OD with Ceramic	10891793
2+	413 Rank=2	0.150 Rank=2	0.014 Rank=2	R_c 29-36 Rank=1	10.4	174.4	CH	Turn OD with Ceramic	10956584
2	375 Rank=2	0.100 Rank=2	0.015 Rank=2	R_c 33-35 Rank=1	6.7	152.2	-	Turn OD	12007666
2	256 Rank=1	0.250 Rank=3	0.017 Rank=2	R_c 25-30 Rank=0	13.1	88.6	G	Turn OD	12007623
1	423 Rank=2	0.060 Rank=2	0.015 Rank=2	R_c 26-32 Rank=0	4.6	39.6	CR	Turn OD	8449307
3	848 Rank=3	0.140 Rank=2	0.026 Rank=3	R_c 26-32 Rank=0	37.0	239.0	-	N/C Turn OD	8382446
3	761 Rank=3	0.140 Rank=2	0.026 Rank=3	R_c 26-32 Rank=0	32.0	209.0	-	N/C Turn OD	8382446

TABLE 3.1-13 (continued)

Weighting Factors	3	1	2	100	6				
Overall Severity Index	SFM	Depth of Cut	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
2	411 Rank=2	0.140 Rank=2	0.018 Rank=2	R_c 20-25 Rank=0	12.4	86.4	-	N/C Turn OD	10895646
Ranking Criteria	500-UP=R=3 300-499= R=2 100-299= R=1	0.250-UP=R=3 0.060-0.244= R=2 0-0.059=R=1	0.026-UP= R=3 0.01-0.025= R=2 0-0.009= R=1	41-46=R=2 35-40=R=1 0-34=R=0		200-UP=R=3 50-199=R=2 0-49=R=1			

Key: See Table 3.1-3

TABLE 3.1-14

Summary Table for Boring Severity Index Determination

Weighting Factors	3	1	2	100	17				
Overall Severity Index	SFM	Depth of Cut	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
2	197 Rank=2	0.125 Rank=2	0.013 Rank=2	NHS Rank=0	3.8	76.6	G	Bore ID	5507239
3	237 Rank=2	0.125 Rank=2	0.015 Rank=3	R_c 26-32 Rank=0	5.3	104.1	-	Bore ID	8449307
3	294 Rank=3	0.125 Rank=2	0.015 Rank=3	R_c 26-32 Rank=0	6.6	129.2	-	Bore ID	8449307
2	316 Rank=3	0.060 Rank=1	0.015 Rank=3	R_c 26-32 Rank=0	3.4	73.8	-	Bore ID	8449307
3	221 Rank=2	0.187 Rank=3	0.012 Rank=2	BHN 242 248 Rank=0	6.0	115.0	CH	Bore ID	6508898
Ranking Criteria	250-UP=R=3 100-249= R=2 0-99=R=1	0.150-UP=R=3 0.100-0.144 =R=2 0-0.099 =R=1	0.015-UP =R=3 0.012-0.014 =R=2 0-0.013	40-45=R=10 35-40=R=1		100-UP=R=3 50-99=R=2 0-49=R=1			

Key: See Table 3.1-3

The data observed for those operations are presented in Table 3.1-6 for drilling and Table 3.1-7 for tapping. A severity index was established by considering the surface speed, chip load, and aspect ratio. The index has been weighted such that a rank of two represents a high medium severity index and has been assigned a rank of two to be consistent with turning operations. However, if other holes are drilled in the future having an aspect ratio (length to diameter) greater than 3 to 1, another severity index value must be assigned. The deeper the hole the more difficult it is for cutting fluid to reach the chip/tool interface. For this type of operation, a special overall severity index classification of four is assigned.

Tapping operations involve internal thread generation in which the depth of cut is directly proportional to the hole diameter for basically all threads. The tap speed, hole depth and whether through or blind holes are produced are the critical factors for incorporating into a severity index. An overall severity index of two was established for all the tapping operations observed.

3.1.6 Milling Operations

Milling operations at RIA can be placed in three basic categories: face, end, and peripheral milling. These operations are performed on either N/C or conventional machine tools. The N/C equipment was operated at speed ranges of 400-700 SFM, somewhat higher than the 100-350 SFM range of the conventional machines. Many of the face milling operations were performed without the use of a cutting fluid.

The milling operations were organized into three categories in order to define their severity index more accurately. These categories are face milling, end milling and conventional peripheral milling. Each of these utilize different tool geometries and have different parameter ranges which are presented in Tables 3.1-15 to 3.1-17.

The feed per tooth and the feed rates varied depending on the operation. The hardness, except for two cases, of all the operations observed, was less than R_c30 which machines more readily than R_c35. The exceptions were given special considerations when their severity index was developed.

Each of the three categories of milling was separately ranked for its severity in speed, feed per tooth, feed rate and hardness through the use of a one to three interval scale, three being the most severe and one being the least severe. Also, each milling operation's metal removal rate was calculated and the mode of the observed tool wear was specified. The overall severity ranking was attributed to the combination of all of these factors.

Establishment of a quanitative severity index required combining these five factors (tool wear mode was not used) in a logical manner. A weighting technique was developed which involved assigning a coefficient of relative importance to each of the five factors. Summation of the five products then provides a number representing the relative severity of the various RIA milling operations. This number was then converted back to a one to three interval scale, three being the most severe and one the least. This procedure is illustrated in Tables 3.1-15 through 3.1-17.

TABLE 3.1-15

Summary Table for Face Milling Severity Index Determination

Overall Severity Index	SFM	Feed/Tooth (in.)	Feed Rate (in/min)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
Weighting Factors	3	1	2	200	2				
1	314 Rank=2	0.002 Rank=1	4-8 Rank=3	NHS Rank=0	60	133	CH	Face Milling N/C, Dry	8449309
3	702 Rank=3	0.003 Rank=2	12.5 Rank=3	R_c 25-30 Rank=0	316	649	-	Face Milling Dry	10884271
2	650 Rank=3	0.002 Rank=1	7.6 Rank=3	R_c 31-38 Rank=1	119	454	CH	Face Milling Dry	7793063
2	629 Rank=3	0.002 Rank=1	8.0 Rank-3	NHS Rank=0	121	258	CH	Face Milling N/C	8444309
Ranking Criteria	500-UP=R=3 300-499=R=2 0-299=R=1	0.005-UP=R=3 0.003-0.0049 =R=2 0=0.0029=R=1	7-UP=R=3 3-6.9=R=3 0-2.9=R=1	42-46=R=2 35-41=R=1 0-34=R=0		500-UP=R=3 250-499=R=2 0-249=R=1			

Key: SFM = Tool velocity, surface feet per minute.
Feed per Tooth = Amount of material each tooth removes in inches.
Feed Rate = Tool advancement rate, inches per minute.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.
R = Rank

TABLE 3.1-16

Summary Table for End Milling Severity Index Determination

	SFM	Feed/Tooth (in.)	Feed Rate (in/min)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
Weighting Factors	3	1	2	200	4				
Overall Severity Index									
1	60 Rank=1	0.0015 Rank=1	1.5 Rank=1	NHS Rank=0	2	14	-	N/C End Milling	8447309
3	334 Rank=2	0.001 Rank=1	2.0 Rank=1	NHS Rank=0	40	169	-	N/C End Miling	8447309
2	62.4 Rank=1	0.008 Rank=3	2.0 Rank=1	NHS Rank=0	12	56	-	End Milling	7133213
1	32 Rank=1	0.004 Rank=2	2.0 Rank=1	NHS Rank=0	3	19	CH	End Milling	6532032
1	63 Rank=1	0.0016 Rank=1	3.0 Rank=2	NHS Rank=0	4	24	-	N/C End Boring,N/C	8441309
1	57 Rank=1	0.003 Rank=2	3.0 Rank=2	NHS Rank=0	6	33	-	End Milling Boring,N/C	8449300
1	64 Rank=1	0.001 Rank=1	6.0 Rank=2	NHS Rank=0	5	28	-	End Milling Boring,N/C	8449300
Ranking Criteria	500-UP=R=3 300-499=R=2 0-299=R=1	0.005-UP=R=3 0.003-0.0049 =R=2 0-0.0029=R=1	7-UP=R=3 3-6.9=R=3 0-2.9=R=1	42-46=R=2 35-41=R=1 0-34=R=0		150-UP=R=3 50-149=R=2 0-49=R=1			

Key: See Table 3.1-15

TABLE 3.1-17

Summary Table for Conventional Peripheral Milling Severity Index Determination

Weighting Factors	3	1	2	200	2				
Overall Severity Index	SFM	Feed/Tooth (in.)	Feed Rate (in/min)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
2	314 Rank=2	0.005-0.008 Rank=3	3-5 Rank=2	NHS Rank=0	150	313	-	N/C Slot Milling	8449309
3	398 Rank=2	0.004-0.007 Rank=3	5-8 Rank=3	NHS Rank=0	267	549	CH	N/C Slide Milling	8449309
1	314 Rank=2	0.003-0.004 Rank=2	3-4 Rank=2	NHS Rank=0	53	118	CH	N/C Side Milling	8449309
2	47 Rank=1	0.005 Rank=3	2.63 Rank=1	R_c 42-46 Rank-2	7	422	-	Peripheral Milling	7791379
Ranking Criteria	500-UP=R=3 300-499=R=2 0-299=R=1	0.005-UP=R=3 0.003-0.0049 =R=2 0-0.0029=R=1	7-UP=R=3 3-6.9=R=3 0-2.9=R=1	42-46=R=2 35-41=R=1 0-34=R=0		500-UP=R=3 250-499=R=2 0-249=R=1			

Key: See Table 3.1-15

3.1.7 Grinding Operations

Grinding requirements for Rock Island Arsenal are somewhat different from most commonly encountered grinding operations. Grinding is typically used to machine hard or difficult to machine parts where other types of machining processes cannot be utilized. The unique feature at Rock Island is that the bulk of the material being ground is unhardened 4100 series steels. The surfaces being ground are most commonly wear surfaces which must be ground to specific surface finishes to provide for adequate film lubrication during service, or to provide a sufficiently qualified surface for subsequent chrome plating. The chrome plating is used to provide superior wear resistance during service. Several production grinding operations were examined. These operations were done either on cylindrical or surface grinders and are presented in Table 3.1-8.

Observations regarding grinding equipment at Rock Island Arsenal were made and may be summarized by the following:

1. Spindle speeds are governed by constant speed AC motors. Thus the actual surface speeds of the wheels decrease as the wheel radius decreases during use.

2. Infeeds are, in general, except for stellite, 0.001 inch for roughing operations and 0.0005 inch for finishing operations. These values can be attributed to limitations imposed by the flexibility of the parts being ground. Any larger infeed values would cause excessive part deflection creating tolerance problems.

3. On cylindrical parts, the cross feeds are larger than those normally found in the Machinability Data Handbook. This would tend to load the part being ground in the axial direction, the direction in which the part is most rigid. The metal removal rates can then be increased without sacrificing tolerance.

4. For the surface grinding operations observed, the wheels were six inches in width. A large crossfeed could be used while producing a good finish with these wide wheels.

5. Specific levels of cross feed were found to be subject to considerable variation. Machine operators were free to select parameters on an individual basis to meet surface finish and size requirements.

6. Dressing was infrequently done as compared to most operations involving intricate forms or difficult-to-grind high temperature alloys. In most cases, dressing was done once every hour and was primarily required to remove wheel loading.

The major observation is that all current grinding operations may be grouped into two severity index categories. However, since the grinding speeds are an order of magnitude higher than milling and the effective tool geometries involve highly negative rake angles, special severity indices will have to be established to adequately treat the grinding process requirements. A medium value overall severity index value of two is

assigned to all of the grinding operations observed except for stellite. These operations are similar to the medium duty turning operations. They were all performed on 4100 series steels and required cooling properties from the applied cutting fluid.

The grinding of the stellite barrel operation requires the assignment of a higher overall severity index value. This operation is far more severe than even grinding hardened tool steel. This is because stellite retains a high yield strength at very high temperatures. The grinding process has been reported to take place at approximately 2000 degrees F. Stellite still retains much of its yield strength at high temperatures and causes the grinding wheel to wear at a high rate especially at the corners. This results in extremely low G-ratios compared to grinding 4100 series steels. Therefore, a special overall severity index value of five is assigned to stellite grinding.

3.1.8 Broaching Operations

Broaching is typically a low speed cutting operation used for the generation of various two dimensional forms. Because of the low speeds involved, the most commonly experienced type of tool wear is of the built-up-edge type. A cutting fluid for these operations should have excellent lubricating properties with adequate E.P. additives.

There was only one broaching operation in production during visits to the Arsenal. This operation consisted of producing the rifling internally in 50 caliber machine gun barrels. The fluid was applied at 300 psi through a collet where the broach entered the part. Poly-Form Oil's Topaz 7/150 oil was used for the operation and seemed to perform adequately. Parts were inspected 100% for tearing in the as-cut surface. As soon as tearing was evident, the broach tool was sent to the tool room for resharpening.

All of the broaching observed was for the 50 caliber machine gun barrels, part number 7793146. The following data are typical for this operation:

SFM:	10 ft/min
Length of Cut:	2.5 ft
Rise/Tooth:	0.0005 inch
Total Depth of Cut:	0.010 inch lands
	0.050 inch grooves

The broaching operation observed, like the stellite grinding operation, is an extremely severe operation which requires a special overall severity index value. The severity index value for broaching is five.

3.1.9 Future Uses of the Severity Index

By following the procedures described in the preceding subsections, a severity index could be calculated for any new machining operation that the Arsenal may be required to perform. This index may be used as a planning or cost estimating tool. Fill in the blank type severity index forms are provided in Appendix A. A sample form for boring is displayed in Figure 3.1-2. For example, a new part has to be bored having the following machining parameters: Part Number: 7771777, SFM: 255 Doc = .125,

Boring Severity Index Determination Table

Weighting Factors	3	1	2	100	17				
Overall Severity Index	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
Ranking Criteria	250-UP=R=3 100-249= R=2 0-99=R=1	0.150-UP=R=3 0.100-0.144 =R=2 0.0.099 =R=1	0.015-UP =R=3 0.012- 0.014 =R=2 0.0.013 =R=1	40-45=R=10 35-40=R=1		100-UP=R=3 50-99=R=2 0-49=R=1			

Key: SFM = Workpiece velocity, surface feet per minute.
Depth of Cut = Tool engagement normal to feed direction, inches.
Feed Rate = Tool advancement rate, inches per revolution.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping.
CR = Cratering.
G = Balance between cratering and tool flank wear.

Figure 3.1-2 Sample Severity Index Determination Sheet.

Feed: .015, Hardness = 32 Rc. First, the initial data are filled in on the form (see Figure 3.1-3). Second, the metal removal rate is calculated (12"/ft x 255 SFM) (.125") (.015"/rev) = 5.74.

Next, the basic operation severity rank must be calculated. In order to accomplish this each machining parameter must be ranked. The ranking value is determined by comparing the parameter value to the chart at the bottom of the parameter's column. In the case of SFM, the rank for 255 SFM would be 3 (see Figure 3.1-3). Once the ranks are calculated, the summation of the products of the weighting factor with their associated rank number is calculated to form the basic operation severity rank. This operation is displayed below in detail for this example:

$$(R_{Speed} = 3)(WF_{Speed} = 3) + (R_{Doc} = 2)(WF_{Doc} = 1)$$

$$+ (R_{Feed} = 3)(WF_{Feed} = 2) + (R_{Hardness} = 0)(WF_{Hardness} = 100)$$

$$+ (MRR = 5.7)(WF_{MRR} = 17) = 113.9 = \text{Basic Operation Severity Rank}$$

<u>Key:</u> R = Rank
WF = Weighting Factor
Doc = Depth of Cut

The final step is to calculate the overall severity index. At the bottom of the column of the basic operation severity rank is the table of values used to determine this value. For our example the overall severity rank should be 3. A considerable amount of discussion preceded selection of three basic severity index ranges. It was felt that a larger number of range intervals would defeat the basic purpose of this program, to simplify fluid selection procedures.

3.2 Cutting Fluid Manufacturer Survey and Test Fluid Selection Criteria

In general, experience has shown most manufacturing facilities have not given cutting fluids the priority they should receive. This portion of the report will provide some background on cutting fluids and emphasize their importance in the manufacturing process. It will look at the different types of fluids available, their basic composition, and discuss criteria for testing. The purpose of this section is to describe the types of cutting fluids available, the benefits of each type, and criteria for cutting fluid selection.

3.2.1 Cutting Fluid Manufacturer Survey

The total of 23 cutting fluid manufacturers and 84 cutting fluids were included in the Phase I and Phase II program evaluations. These manufacturers and associated cutting fluids are first displayed in Table 3.2-1. This table has the fluids divided into general categories often associated with cutting fluids: heavy duty, medium duty and

Boring Severity Index Determination Table

Weighting Factors	3	1	2	100	17				
Overall Severity Index	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
	255	*.125*	*.015*	*32 Rc*					
	Rank=*3*	Rank=*2*	Rank=*3*	Rank=*0*	*5.74*	*113.9*		*Bore ID*	*7771777*
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
Ranking Criteria	250-UP=R=3 100-249= R=2 0-99=R=1	0.150-UP=R=3 0.100-0.144 =R=2 0.0.099 =R=1	0.015-UP =R=3 0.012- 0.014 =R=2 0.0.013 =R=1	40-45=R=10 35-40=R=1		100-UP=R=3 50-99=R=2 0-49=R=1			

Key:
SFM = Workpiece velocity, surface feet per minute.
Depth of Cut = Tool engagement normal to feed direction, inches.
Feed Rate = Tool advancement rate, inches per revolution.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping.
CR = Cratering.
G = Balance between cratering and tool flank wear.

Figure 3.1-3 An Example of How to Use the Severity Index Determination Table.

TABLE 3.2-1

Candidate Cutting Fluids Categorized by Type and Manufacturer's Listed Application

	Neat Oil	Emulsion	Semi-Synthetic	Full Synthetic
HEAVY DUTY	Do-All Co. No. 240 Econ. Lab Magnus CB-66 Gulf Oil Gulfcut 21D Mobil Oil Mobilmet Gamma VACMOL 2105 Poly-Form Oils Topaz 7/100 Sun Petroleum Sunicut 352 Valvoline Oil 1023 14555 Van Straaten 5299 Series	Cincinnati Milacron Cimperial 1011 Do-All Power-Cut 390 EHD DuBois Lubricoolant 940 Gulf Oil Gulfcut Heavy Duty International Refining Irmco 335 Master Chemical Trim RD2-83A Norton Wheelmate 811 Stuart SOLVOL 6633 DASCO 1149 CODOL 0748	Fremont 7036 Norton Wheelmate 674	Cincinnati Milacron Cimcool 400 DuBois Lubricoolant 925 Econ. Lab Magnus Div. MX5080 SYNLUBE HD Fremont 7012 Master Chemical Trim HD Trim EP Pillsbury Kook Kut 5500 Stuart DAS COOL 4408B Valvoline Oil ADCOOL 3 Van Straaten 951
MEDIUM DUTY	Econ. Lab Magnus CC-6 Gulf Oil Gulfcut 11D Mobil Oil MobilMet Sigma Valvoline Oil 1002	Econ Lab Magnus Magna-Cool 60 Gulf Oil Gulfcut Soluble E. F. Houghton Hocut 3210-X International Ref. Irmco 303 Master Chemical Trimsol Trim CE McGean Norsol 50196 Mobil Oil MobilMet S-125 Ohio Industrial Res. Mastercut Pillsbury SWORD CUT 1741 Stuart DASCO 1086 Sun Petroleum Emulsun 51 Valvoline Oil ADSOL 2	Cincinnati Milacron Cimcool Five Star 40 Fremont 7030 E. F. Houghton Hocut 711 Johnson Wax JON-COOL 800 McGean Norsol 5090 Pillsbury SYN PYNK 8 Stuart DASCOOL 502 Aluminum DASCOOL 4379 Van Straaten 550-P	Cincinnati Milacron Cimfree 238 Do-All Co. Power Cut HD-600 Fremont 7011 E. F. Houghton Hydra-Cut 496 International Ref. Irmco 103 Norton Co. Wheelmate 689 Pillsbury KOOL KUT 5555 KOOL KUT 5584 Poly-Form Oils Poly Aqua Stuart DASCOOL 427 Tapmatic ME 11 Valvoline Oil ADCOOL 2 Westmont Bio-Cool 500 Wynn Oil Co. 951-1 Synthetic 941 Synthetic
LIGHT DUTY	Econ. Lab Magnus DO-5A	Do-All Co. 470 Master Chemical Trim LC Mobil Oil MobilMet 140 Valvoline Oil ADSOL 1		Fremont 7013 Master Chemical Trim 9106-CS Valvoline ADCOOL 1

1990-D

light duty. Also, this table further divides the fluids into the specific types of cutting fluids: emulsions, semi-synthetics and full synthetics. These categories were developed from information supplied by manufacturers. Each manufacturer completed a survey form for the product that was recommended for each RIA manufacturing operation. The form used for products diluted in water is displayed in Figure 3.2-1. Manufacturers specifying neat oil products were required to complete the form reproduced in Figure 3.2-2.

These classification categories vary from manufacturer to manufacturer. However, for consistency throughout this report, the classification categories will be defined as follows: A heavy duty cutting fluid is one which contains one or more chemical additives such as sulfur or a special chemical that provides extreme pressure (E.P.) lubrication in addition to its composition which provides lubrication. An example is an emulsion which has sulphur and chlorine. The oil in the emulsion provides general lubrication while the sulphur and chlorine will provide extreme pressure lubrication. Light duty cutting fluids do not contain E.P. additives or enhanced lubrication properties. Medium duty cutting fluids have a composition that provides lubrication and in some cases small amounts of a single E.P. additive. An emulsion with .5% phosphorus is an example of a medium duty cutting fluid. The wetting ability of a cutting fluid must also be taken into account. Wetting can be described as the ability of a fluid to get between two surfaces by reducing the interfacial tension between them. A fluid with an extreme wetting action could be classified as heavy or medium duty and not contain any E.P. additives because it has the ability to get between the chip/tool/workpiece interface.

An emulsion or soluble oil is a cutting fluid containing approximately forty to sixty percent oil. Emulsions are generally opaque and have the ability to mix in both water and oils. Semi-synthetics typically contain from five to twenty percent oil and are translucent. As with emulsions, they have the ability to mix with water and dissolve oil. Full synthetics contain no natural oil and most full synthetics are immiscible with oils. They are generally transparent due to the fact full synthetics are true solutions.

3.2.2 Initial Screening Tests

A program to technically evaluate all available present and future cutting fluids would be a virtual impossibility. Therefore, methods were developed to reduce the number of fluids to be tested. Three tests were conducted on all the fluids made available during Phase I and Phase II for initial screening: rust tests, bacteria tests and residue tests.

Rust Test:

The ability of a cutting fluid to inhibit the formation of rust is very important. Equipment efficiency will be reduced if they contained a cutting fluid that would allow rusting to occur. Also, rust prevention is very important for tooling and fixtures. Therefore, the initial criteria of a cutting fluid would be its ability to inhibit rust.

The rust test was conducted by putting 10 grams of freshly drilled cast iron chips on a piece of filter paper placed in a petri dish. Then 10 ml of cutting fluid mixed to the manufacturer's turning dilution ratio was poured over the chips. The test lasted

FLUID CHARACTERIZATION QUESTIONNAIRE
FOR PRODUCTS DILUTED IN WATER

Company Name: ______________________________ Fluid Name: ____________

1. Choose Generic Type: ________ Emulsion
________ Synthetic
________ Other ______________________________

2. What are the dilution ratios for the following machining operations using 4100 steel and 6000 aluminum? (Leaving a blank space will indicate the fluid is not applicable.)

	4100 Steel		6000 Aluminum	
Operation	HSS	Carbide	HSS	Carbide
Turning	______	______	______	______
Milling	______	______	______	______
Grinding	______	______	______	______
Drilling	______	______	______	______
Broaching	______	______	______	______

3. Are there special mixing requirements?

________ None ________ Premix ________ Other ______________________________
____

4. To what degree will any of the following factors affect the stability of the emulsion?

	No Effect	Medium Effect	Strong Effect
Temperature	______	______	______
Bacteria	______	______	______
Chip Material	______	______	______

5. Which of the following additive types are in the product?

________ Sulfur ________ Phosphorous
________ Bromine ________ Anti-rust
________ Oils ________ Anti-foam
________ Others ______________________________
____

6. What color is this product? ______________________________

7. How strong an odor does this product have as mixed?

________ None ________ Weak ________ Medium ________ Strong

Figure 3.2-1. **Data collection questionnaire used for products diluted in water.**

8. Will this fluid have any of the following effects on equipment?

	None	Slight	Strong
Paint	______	______	______
Rust Inhibition	______	______	______
Lubricants	______	______	______
Stain Tools/Work Pieces	______	______	______
Misting	______	______	______
Foaming	______	______	______

9. Are there additive replenishment packages available for this product?

_______ Yes _______ No

10. What procedure must be taken to dispose of this product into a waste treatment system?

____

____

____

11. Describe the recommended concentration testing method.

____

____

____

12. What is the cost and delivery time of this product?*

Break Point		Drum	Tank Wagon	Tank Car
1	Gallons	_____to_____	_____to_____	_____to_____
	Cost/Gal	______	______	______
	Delivery Time	______	______	______
2	Gallons	_____to_____	_____to_____	_____to_____
	Cost/Gal	______	______	______
	Delivery Time	______	______	______
3	Gallons	_____to_____	_____to_____	_____to_____
	Cost/Gal	______	______	______
	Delivery Time	______	______	______
4	Gallons	_____to_____	_____to_____	_____to_____
	Cost/Gal	______	______	______
	Delivery Time	______	______	______

* Available current price listings and delivery schedules may be provided.

Figure 3.2-1. (continued)

FLUID CHARACTERIZATION QUESTIONNAIRE
FOR NEAT OIL PRODUCTS

Company Name: ______________________ Fluid Name: ______________

1. What is the type of base oil? ______________________

2. Describe the physical characteristics:

   Viscosity ______________ Color ______________

   Flash Point ______________ Fire Point ______________

3. Which of the following additive types are in the product:

   ________ Sulfur ________ Fatty Acids

   ________ Bromine ________ Phosphorous

   ________ Others ______________________

   ____

4. Indicate which machining operations and materials that can be used with this product. (Leaving a blank space will indicate the fluid is not applicable.)

Operation	4100 Steel HSS	4100 Steel Carbide	6000 Aluminum HSS	6000 Aluminum Carbide
Turning	______	______	______	______
Milling	______	______	______	______
Grinding	______	______	______	______
Drilling	______	______	______	______
Broaching	______	______	______	______

5. How strong an odor does this fluid have?

   ________ None ________ Weak ________ Medium ________ Strong

6. Will this product have any of the following effects on equipment?

	None	Slight	Strong
Paint	______	______	______
Rust Inhibition	______	______	______
Lubricants	______	______	______
Stain Tools/Work Pieces	______	______	______
Misting	______	______	______
Foaming	______	______	______

7. What procedure must be taken to dispose of this product?

____

____

____

Figure 3.2-2. Data collection questionnaire used for neat oil products.

8. Is it economically feasible to recycle this product:

_______ Yes _______ No

9. Describe the recommended concentration testing method.

____

____

____

10. Are there additive replenishment packages available for this product?

_______ yes _______ No

11. What is the cost and delivery time of this product?*

	Break Point	Drum	Tank Wagon	Tank Car
	Gallons	____ to ____	____ to ____	____ to ____
1	Cost/Gal	________	________	________
	Delivery Time	________	________	________
	Gallons	____ to ____	____ to ____	____ to ____
2	Cost/Gal	________	________	________
	Delivery Time	________	________	________
	Gallons	____ to ____	____ to ____	____ to ____
3	Cost/Gal	________	________	________
	Delivery Time	________	________	________
	Gallons	____ to ____	____ to ____	____ to ____
4	Cost/Gal	________	________	________
	Delivery Time	________	________	________

* Available current price listings and delivery schedules may be provided.

Figure 3.2-2. (continued)

one week. However, the fluids that did allow rusting usually did so in a few hours. The fluids that did not pass the rust test are:

Cimperial 1011, Cincinnati Milacron

Irmco 103, International Chemical Co.

Wheelmate 811, Norton Company

Poly Aqua, Poly-Form Oils

911, Wynn Oil Company

1149, D. A. Stuart Oil Company

Norsol SO 90, McGean

Jon Cool 800, Johnson Wax

Bacteria Test

Observations at RIA indicated the number one cutting fluid problem was anerobic bacteria growth. Each test fluid was tested for its ability to resist bacteria.

Fifteen ml of the test fluid mixed to the turning dilution ratio specified by the fluid manufacturers was inoculated with one drop of spoiled cutting fluid secured from RIA. This screening test gave no results after a two-week incubation period at room temperature. This indicated that each test fluid contained a sufficient quantity of biocide to control a minimal amount of bacteria contamination. However, this is not representative of what may occur with daily recontamination.

Residue Test:

Another important property of a cutting fluid is what form of residue may be left behind after the water evaporates from it. Heavy or waxy residues could inhibit machine motions or if it forms hard crystalline deposits machine operation can score delicate wear surfaces.

Ten milliliters of test fluid mixed to the turning dilution ratio specified by the fluid manufacturers was allowed to stand at room temperature for one week. The only fluids that were questionable were Master Chemicals full synthetic 9106CS and Poly Form Oils Poly Aqua that left a salty residue. The rest of the test fluids left either a mildly gummy or an oily residue. The gumminess of the residues was judged not to be extremely objectionable.

3.2.3 Criteria for Final Fluid Selection

Two factors were kept in mind when analyzing the various machining operations: the need for cooling and the need for lubrication. A high temperature machining operation such as grinding requires more cooling than lubrication. Milling, which is a lower temperature operation, requires more lubrication properties. However, some high temperature operations will experience a decrease in temperature if a lubrication additive is utilized. When such conditions exist, careful process analysis is required before a cutting fluid is selected.

Cooling is the ability of the cutting fluid to draw heat from the tool workpiece and chip. Lubrication is a property the cutting fluid has which allows it to produce a thin film between the tool/workpiece interface and tool/chip interface. This film reduces the friction between these surfaces and reduces the work required to accomplish the operation which reduces the heat generated. More specifically, it reduces the length of the cutting shear plane.

The state of the art of cutting fluid lubrication has advanced substantially in the last few years. Initially, natural oils and animal fats were used for lubrication. Currently, extreme pressure (E.P.) additives have come into wide use. An E.P. additive will break down and form a thin film layer at selective temperatures, depending on the additive, which will increase the lubrication capability of the oil on synthetics in the cutting fluid. Different types of E.P. additives perform different and in some cases when combined together will produce a synergistic effect and fluid performance will increase at a higher rate than the sum of that produced individually. Also, wetting agents have been developed which increase the effectiveness of the E.P. additives and lubrication properties of the fluid. The combination of all these factors results in the total efficiency of a cutting fluid under a certain set of conditions. Cutting fluid efficiency seems to be governed by the temperature and pressure the machining operation is generating. This is why some cutting fluids work on some machining operations while others will not. For example, combined sulphur does not become an effective lubricant until a temperature of approximately 1200 degrees F is reached.

Initially, a possible fluid selection matrix was designed. Each basic machining operation was coupled with the four types of cutting fluids: full synthetics, semi-synthetics, emulsions and neat oils. Then as the machining severity index was developed, this initial matrix was reduced to the one exhibited in Table 3.2-2. Each fluid type was matched to RIA's machining operations. The major difficulty after this point was selecting which fluids would be actually tested. A computer program was designed to group all of the fluids by general type and then by chemical composition. Other pertinent data, such as mixability, effects on equipment paint, ease of waste disposal, foaming, and cost to fill a 50 gallon sump, were displayed on the computer printout (see Table 3.2-3). These data were used to choose the test fluids. The exact logic is as follows:

1. Grouped All Fluids

   Each cutting fluid was grouped by generic type and then by degree of fortification. Based on knowledge of its chemical composition, all cutting fluids in each strength category with similar additives were assumed to perform the same as other fluids of the same generic type and strength.

2. Selected Fluids From Each Generic Type

   Each machining test contained fluids from each generic type and strength categories applicable, as dictated by the machining severity index.

TABLE 3.2-2

RIA TEST FLUID SELECTION MATRIX

Operation	Emulsion			Semi-Synthetic			Full Synthetic			OIL		
	LD	MD	HD	LD	MD	HD	LD	MD	HD	LD	MD	HD
Grinding	X	X		X	X		X	X				X
Turning & Boring		X	X		X	X		X	X			
Milling		X	X		X	X		X	X			X
Drilling & Tapping		X				X			X			
Broaching												X

Key: LD = Light Duty
MD = Medium Duty
HD = Heavy Duty

TABLE 3.2-3 RIA CUTTING FLUID DATA ANALYSIS

COMPANY NAME	FLUID NAME	TYPE	S	C	P	CS	P	R	L	S	M	F	MIX	W	T.D/R	C50-T	G.D/R	C50-G	C/GAL
VALVOLINE	ADSOL 1	E					N	?	?	N	S	S	N	A	20	8.71	35	5.08	3.66
MASTER CHEMICAL	TRIM LC	E				+	N	N	N	N	N	N	N	A	20	17.88	30	12.11	7.51
OHIO IND. RES.	MASTERCUT	E				.S	N	N	N	N	S	N	N	A	20	12.80	40	6.56	5.38
MOBIL OIL	MOBILMET 140	E				?	N	S	S	N	N	N	N	A	20	8.54	20	8.54	3.59
MOBIL OIL	MOBILMET S-125	E				?	N	S	S	N	N	N	N	A	15	12.78	15	12.78	4.09
STUART OIL	SOLVOL 6633	E				F	N	G	S	N	N	N	N	A	25	10.63	30	8.91	5.53
INTERNATIONAL R	IRMCO 303	E				FA	N	G	G	N	S	N	N	A	25	14.80	40	9.39	7.78
ECONOMICS LAB	MAGNACOOL 60	E				FT	N	N	S	N	S	N	PRE	A			40	7.48	6.14
VALVOLINE	ADSOL 2	E		C			N	?	?	N	S	S	N	A	20	10.73	40	5.50	4.51
STUART OIL	DASCO 1086	E		C			N	S	S	N	N	N	Y	A	25	8.73	30	7.32	4.54
SUN OIL	EMULSUN 51	E		C			S	N	S	S	S	N	N	A	20	8.40	40	4.30	3.53
PILLSBURY	SWORD KUT 1741	E		C			N	G	B	N	S	S	N	A	20	16.61	20	16.61	6.98
MASTER CHEMICAL	TRIM CE	E		C			B	G	S	S	S	S	PRE	A	10	35.90	20	18.80	7.98
MASTER CHEMICAL	TRIM SOL	E		C			S	N	B	N	S	N	DI	A	19	19.62	19	19.62	7.85
CIN. MILACRON	CIMPERIAL 1011	E		C		.S	N	N	N	N	S	N	N	A	20	17.50	20	17.50	7.35
VAN STRAATEN	768	E		C		F	N	G	N	N	N	S	N	A	10	32.59	20	17.07	7.17
STUART OIL	CODOL 0748	E		C		F	N	G	S	N	N	S	N	A	25	12:57	30	10.54	6.54
MCGEAN	NORSOL SO196	E		C	P		N	G	N	N	S	S	N	A	30	10.16	35	8.75	6.30
GULF	GULF CUT HD	E	S				S	N	S	N	N	N	N	A	20	9.88	40	5.06	4.15
STUART OIL	DASCO 1149	E	S			F	N	S	S	N	N	S	N	A	25	14.78	30	12.40	7.69
INTERNATIONAL R	IRMCO 335	E	S			LA	N	G	G	N	N	N	N	A	40	12.13	40	12.13	9.95
VALVOLINE	ADSOL 3	E	S	C			N	N	N	N	S	S	N	A	25	10.78			5.61
ECONOMICS LAB	E P COOLANT	E	S	C			S	N	S	N	S	N	N	A	20	19.35	40	9.91	8.13
E.F.HOUGHTON	HOCUT 3210-X	E	S	C			N	G	S	N	N	S	N	A	25	15.57	40	9.87	8.10
DUBOIS CHEMICAL	LUBRICOOLANT940	E	S	C			S	G	S	S	S	N	N	A	20	23.09	30	15.64	9.78
MASTER CHEMICAL	TRIM RD2-83A	E	S	C			B	N	N	N	N	N	P	A					10.71
NORTON	WHEELMATE 811	E	S	C			N	N	N	N	N	N	N	A	20	22.26	20	22.26	9.35
DOALL	POWER-CUT 390	E	S	C		F	N	G	S	S	S	S	N	A	20	22.61	40	11.58	9.50
DOALL	470 SOLUBLE OIL	E AL					N	S	S	N	S	S	N	A	10	26.36	30	9.35	5.88
GULF	GULFCUT SOL AL	E AL	S				S	N	S	N	S	N	N	A	20	6.90	50	2.84	2.90
MASTER CHEMICAL	9106 CS	FS					B	N	B	N	N	N	N	A			24	13.80	6.98
WYNN OIL	941 SYN	FS					S	N	N	N	S	N	N	A	20	11.07	30	7.50	4.65
VAN STRAATEN	951	FS					S	N	S	N	S	N	N	A	10	25.81	20	13.52	5.68
WYNN OIL	951-1 SYN	FS					S	S	N	N	S	N	N	A	25	13.15	50	6.70	6.84
VALVOLINE	ADCOOL 1	FS					B	?	?	N	S	S	N	A	20	9.00	40	4.60	3.78
STUART OIL	DASCOOL 427	FS					S	B	S	N	N	N	N	A	30	6.91	35	5.95	4.29
STUART OIL	DASCOOL 4408B	FS					S	G	S	N	N	N	N		20	14.26			5.99
TAPMATIC	ME II SUPER	FS					S	S	N	N	N	S	P	B	40	22.56	80	11.41	18.50
POLY-FORM OILS	POLY-AQUA	FS					S	N	N	N	N	N	N	A	25	10.19	30	8.54	5.38
CIN. MILACRON	CIMCOOL 400	FS				++	N	G	N	N	N	N	N	R	20	19.28	25	15.57	8.10
STUART OIL	4428-1 DASCOOL	FS				?	S	G	S	N	N	N	N	?	20	12.73	30	8.62	5.35
WESTMONT I.PROD	BIO-COOL 500	FS				?	N	B	N	N	N	N	N	Z	20	15.00	40	7.68	6.30
JOHNSON WAX	JON COOL 803	FS				?	N	G	S	N	N	N	N	A	20	19.07	40	9.76	8.01
ECONOMICS LAB	MX5080	FS				?	N	N	N	N	N	N	N	Z	30		40		
ECONOMICS LAB	SYN LUBE HD	FS				?	N	N	S	N	N	N	N	A	30	19.22	40	14.53	11.92
CIN. MILACRON	CIMFREE 238	FS				FA	S	N	N	N	N	N	N	A	25	13.61	30	11.41	7.08
INTERNATIONAL R	IRMCO 103	FS				FS	N	G	S	N	N	N	N	A	25	11.25	30	9.43	5.85
PILLSBURY	KOOLKUT 5584 TC	FS				G	N	G	B	N	S	N	N	A	20	23.92	30	16.20	10.05
NORTON	WHEELMATE 689	FS				P	N	N	N	N	N	N	N	A	20	18.19	20	18.19	7.64
VALVOLINE	ADCOOL 2	FS				PG	B	?	?	N	S	S	N	A	20	11.54	40	5.91	4.85
FREMONT	7011 AND AL	FS			P		S	G	N	N	N	S	N	A	30	12.12	60	6.16	7.52
FREMONT	7012 AND AL	FS			P		N	G	N	N	N	S	N	A	30	12.08	60	6.13	7.49
FREMONT	7013	FS			P		S	G	N	N	N	N	N	A	30	12.29	40	9.29	7.62
E.F.HOUGHTON	HYDRA-CUT 496	FS			P		B	G	S	N	N	N	N	A	25	14.67	30	12.30	7.63
DOALL	POWER-CUT HD600	FS			P		B	G	B	N	S	B	N	A	15	26.56			8.58
PILLSBURY	KOOL KUT 5500	FS			P	F	N	G	B	N	N	S	N	Z	25	14.11			7.34
PILLSBURY	KOOL KUT 5555	FS			P	G	N	G	B	N	S	S	N	A	20	16.35	25	13.21	6.87
DUBOIS CHEMICAL	LUBRICOOLANT925	FS			P	N	S	G	S	S	S	S	N	A	20	23.69	40	12.13	9.95

TABLE 3.2-3 (Cont'd) RIA CUTTING FLUID DATA ANALYSIS

COMPANY NAME	FLUID NAME	TYPE	S	C	P	CS	P	R	L	S	M	F	MIX	V	T.D/R	C50-T	G.D/R	C50-G	C/GAL
MASTER CHEMICAL	TRIM HD	FS		C			B	G	S	N	S	S	PRE	A	20	15.71	30	10.64	6.60
MASTER CHEMICAL	TRIM EP	FS	S	C			N	G	S	N	S	S	PRE	A	15	22.96	20	17.50	7.35
VALVOLINE	ADCOOL 3	FS	S	C		PG	S	?	?	N	S	S	N	A	20	17.92	50	7.38	7.53
GULF	GULFCUT 11D/AL	O				FA	S	N	S	N	N	N		R					2.58
ECONOMICS LAB	DO-5A	O				FT	S	N	N	N	S	N		R					6.37
ECONOMICS LAB	CC-6	O	S				S	N	N	N	S	N							6.14
ECONOMICS LAB	C B 66	O	S			FA	?	N	N	N	S	N		R					12.65
MOBIL OIL	MOBILMET SIGMA	O	S			FA	N	S	S	S	N	N		R					2.72
VALVOLINE	PROMAX 1022	O	S			FA	N	S	S	N	S	S		R					2.24
POLY-FORM OILS	7/150	O	S		P	BF	N	N	N	N	N	N		R					4.14
GULF	GULFCUT 21D	O	S	C			N	N	N	N	N	N		R					2.84
DOALL	240 CUTTING OIL	O	S	C		FA	N	N	N	B	S	N		R					5.68
VAN STRAATEN	5299	O	S	C		FA	N	G	N	S	N	S		R					4.31
MOBIL OIL	MOBILMET GAMMA	O	S	C		FA	N	S	S	S	N	N		R					2.79
SUN OIL	SUNICUT 352	O	S	C		FA	N	N	N	S	S	S		R					2.59
MOBIL OIL	VACMUL 2105	O	Y	Y			Y	N	N	N	N	N	N	R					3.15
CIN. MILACRON	S STAR 40	SS					S	N	N	N	N	N	N	A	25	11.01	30	9.24	5.73
STUART	DASCOOL 4379	SS					N	G	S	N	N	S	N	A	25	9.80			5.18
E.F.HOUGHTON	HOCUT 711	SS					S	G	S	N	S	S	N	A	25	8.69	30	7.29	4.52
STUART OIL	DASCOOL 502	SS				F	N	S	S	N	N	S	N	A	25	14.42	30	12.09	7.58
PILLSBURY	SYNPYNK 880	SS				F	N	S	S	N	N	S	N	A	20	7.23	20	7.23	3.84
JOHNSON WAX	JON COOL 800	SS				Y	N	B	S	N	S	S	N	A	20	19.69	30	13.33	8.27
FREMONT	7030	SS			P		S	B	N	N	N	N	P	A	40	9.31	50	7.49	7.64
VAN STRAATEN	550 P	SS		C			?	S	S	N	N	S	N	A	25	11.48	35	8.29	5.97
MCGEAN	NORSOL S090	SS		C			N	G	N	N	N	N	?	A	30	6.93	30	6.93	4.30
NORTON	WHEELMATE 674	SS	S				N	N	N	N	N	N	N	A	20	13.85	0	291.00	5.82
FREMONT	7036	SS	S	C	P		S	G	N	N	N	N	PRE	A	40	10.21	40	10.21	8.38

2047-0

Key for Table 3.2-3

Table Headings

Type = Fluid Type
S = Sulfur
C = Chlorine
P = Phosphorus
CS = Others
P = Effect of fluid on machine paint and workpiece
R = Effect of fluid on rusting machine and workpiece
L = Effect of fluid on machine lubrication
S = Effect of fluid on staining machine and workpiece
M = Fluid mixing requirements
F = Does the fluid foam
W = Waste treatment
T.D/R = Turning dilution ratio
C50-T = Turning 50 gallon sump cost
C.G/R = Grinding dilution ratio
C50-G = Grinding 50 gallon sump cost
B.D/R = Broaching dilution ratio
C50-B = Broaching 50 gallon sump cost
C/Gal = Fluid cost per gallon

Chart Abbreviations

Type: E = emulsion, FS = full synthetic,
O = neat oil, SS = semi-synthetic
S: S = contains sulfur
C: C = contains chlorine
P: P = contains phosphorus
CS: F = FA = Fatty acids, S = Small % sulfur,
FT =PG = P = BF = special additives
P: S = slight, M = medium, B = bad, N = no
R: S = slight, M = medium, B = bad, N = no
S: S = slight, M = medium, B = bad, N = no
M: S = slight, M = medium, B = bad, N = no
W: A = acid split, R = recycle,
Z = can be put through city sewer

3. Performed Special Tests

Additional evaluations were conducted following initial trials of one product from each generic fluid type. For example, a special test was conducted with Master Chemical's Trim HD because it was an emulsion containing both sulphur and chlorine. Another example was the selection of Master Chemical's Trimsol and Cincinnati Milacron's Cimfree 238. These fluids were selected because they are used at the Arsenal.

3.3 Milling and Turning Cutting Fluid Test Results

During the Phase I program effort, an analysis of the RIA manufacturing operation was conducted and presented in section 3.1 of Establishment of a Cutting Fluid Control System (Phase I) by G. A. Lieberman. This analysis revealed that the greatest cost benefit could be achieved if the Phase II program effort be directed to the numerical control milling and turning operations of 4100 series materials. It was concluded that 83 percent of all the operations performed at the Arsenal were milling, turning and grinding. That the 23 percent associated with grinding were not severe operations and that a high performance cutting fluid would offer only a marginal economic benefit. The testing performed in the Phase I effort did reveal several high performance cutting fluids that could be used. Also, two of the tested high performance cutting fluids were already being used at the Arsenal which were achieving good results. Therefore, it was concluded that a high efficiency cutting fluid in the numerical control milling and turning areas could accomplish the following:

1. Reduce Downtime

A reduction of the high hourly machine cost of numerical control milling and turning equipment can be realized if the cutting fluid will not sour over a long period of time. Also, downtime will be reduced when a high performance cutting fluid causes a tool to last longer.

2. Reduce Tooling Cost

Tooling costs can be reduced by eliminating chipping the major mode of tool failure observed at RIA (see Phase I report). A high efficiency cutting fluid will minimize chipping and reduce tool wear.

3. Increasing Productivity

Increased feed rates and speeds can be used with an efficient cutting fluid.

With these goals in mind, the Phase II cutting fluid testing program was designed. The data gathered at the Arsenal during the Phase I program effort was restudied. The initial cutting fluid test data were further refined to predict future test results. The final selection of the cutting fluid testing parameters came after many discussions with the program monitor, the department head of numerical control programming, the general foreman of numerical control turning and the general foreman of numerical

control milling. All of these factors and recommendations were used to develop the parameters used in the cutting fluid testing which follows in the next two subsections.

3.3.1 Milling

This section will review the milling procedures observed at RIA, describe Machining Technology's testing procedures, and discuss the test results. Additional information on the milling process and a detailed discussion of the basic concepts of milling may be reviewed in section 3.6 of Establishment of a Cutting Fluid Control System (Phase I) by G. A. Lieberman. These subjects are presented in the following subsections: review of the RIA milling survey, milling cutting fluid selection, milling test design, Machining Technology's test conditions, milling test results and conclusions.

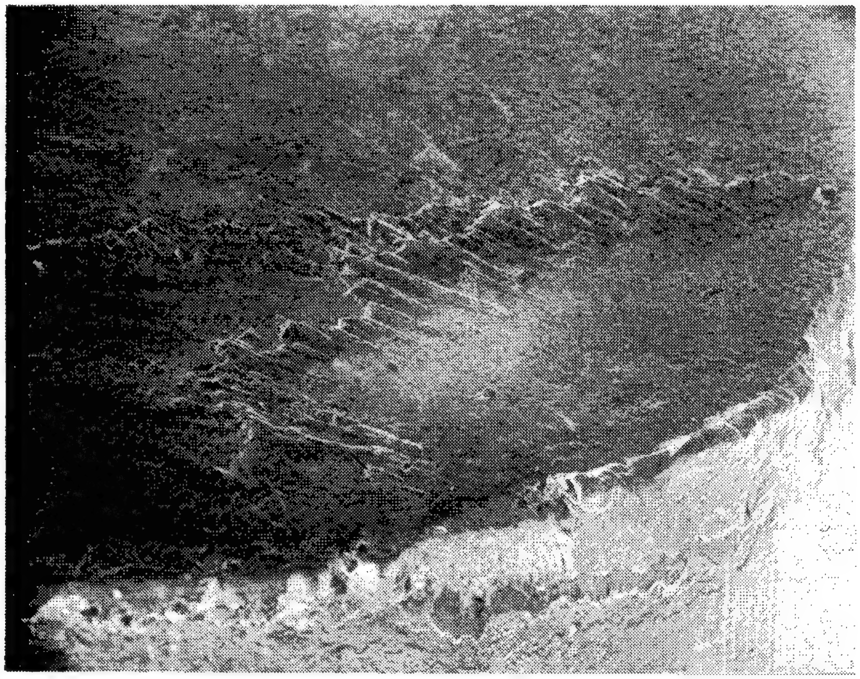
3.3.1.1 Review of the RIA Milling Survey

Milling operations at RIA can be placed in three basic categories: face, end, and peripheral milling. These operations are performed on either N/C or conventional machine tools. The N/C equipment was operated at speed ranges of 400-700 SFM, significantly higher than the 100-350 SFM range of the conventional machines. Many of the face milling operations were performed without the use of a cutting fluid. All of the milling operations are displayed in Table 3.1-5.

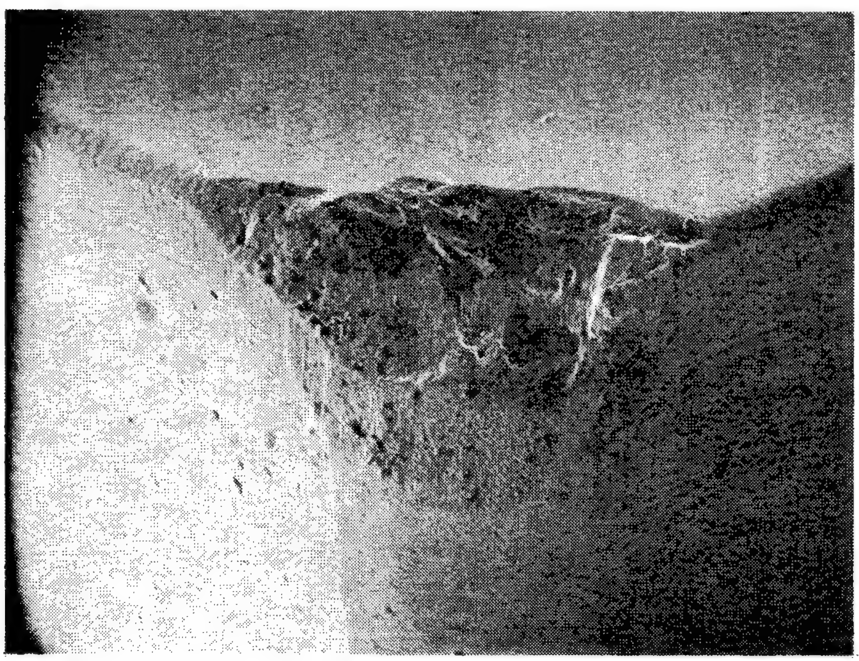
All of the observed tool wear was in the form of chipping. An example of a chipped milling cutter may be observed in Figure 3.3-1. Notice how minimal the other forms of tool wear are in comparison to the microfracturing of the cutting edge. This mode of tool failure can be caused by using a slower surface speed than for which the cutting tool was designed. Another reason could be a lack of rigidity in the setup. The most probable cause of chipping is thermal shock or lack of lubrication at the tool/workpiece interface. This condition may be caused by applying cutting fluids to the tool/workpiece interface in insufficient quantities, using an inadequate cutting fluid for the machining operation, utilizing a cutting fluid below its recommended concentration level, improper positioning the fluid nozzle, or applying a cutting fluid which promotes thermal shock. All of the N/C milling equipment seemed to provide adequate cutting fluid flow on the tool and workpiece. However, many of the older milling machines in Shop M had minimal fluid flow and, in some cases, operations were run dry. Many operations were observed having lower than recommended cutting fluid concentration levels.

3.3.1.2 Milling Test Fluid Selection

Initially, all three generic types of cutting fluids were to be tested and compared to a base fluid without E.P. additives. Also, these fluids would be compared to machining dry (without a cutting fluid). All of the test fluids were considered premium medium to heavy duty fluids except #31. These test fluids may be seen in Table 3.3-1 with their associated 50 gallon sump cost and chemical properties. Fluid #1 was selected as the full synthetic fluid because Phase I tests showed it to be effective and economically superior. Fluid #2 was selected as the test emulsion because it is currently used at RIA. Synthetic fluid #4 was selected because it was the only



Chipping observed during vertical boring of Part No. 8449307. Material: 4140 steel forging; Hardness: R_c 26-32; SFM: 237; Feed: 0.015 in/rev; Doc: 0.125; Fluid: Trimsol 30:1; Tool: Sandvik SNG 633-1025-82464; Machine: Bullard #21560. (50X)



Chipping observed during N/C milling of Part No. 8449309. Material: 4140 steel casting; Hardness: NHS; SFM: 629; Feed: 8 in/min; Chip Load: 0.002; Fluid Trimsol 30:1; Tool: Insert #SPG-422B; Tape: MM027A: Tool: 0914; Machine: K&T N/C Mil #2252. (50X)

Figure 3.3-1. Examples of Chipping.

TABLE 3.3-1

MILLING FLUIDS SELECTED FOR TESTING

Fluid #	Fluid	Manufacturer	Type	Strength	Chlorine	Sulfur	Other	50 Gal Sump Cost
1*	Cimfree 238	Cincinnati Milacron	FS	MD			++	$13.61
2*	Trimsol	Master Chemical	E	MD	C			$19.62
4	Cimcool 400	Cincinnati Milacron	FS	HD			+++	$19.28
8	DASCOOL 502	Stuart Oil	SS	HD			++	$14.42
31	SYN PYNK 880	Pillsbury	SS	LD				$ 7.25
0	VACMUL	Mobil Oil	O	HD	C	S		$157.50

Key:
O = Oil
E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic
LD = Light Duty
HD = Heavy Duty
MD = Medium Duty
C = Chlorine
S = Sulfur
+ = Others
* = Currently Used at RIA

synthetic that had an oily residue and had enhanced lubrication properties. The semi-synthetic #8 was chosen because its properties revealed an extreme wetting ability. Fluid O was selected because it is a typical sulphur chlorinated oil.

3.3.1.3 Milling Test Design

All of the milling tests were conducted at the average milling parameters and with the hardest material used at RIA. These test parameters are as follows:

Tooling:	Valenite MSN75-168-4R3-125, end mill tool holder Valenite SNEA-432, VC-55 carbide insert
SFM:	370
Chipload:	.005 inches/tooth
Feed:	3.9 inches/min.
Cutter Diameter:	1.680 inches
Depth of Cut:	.050 inches
Material:	4140 steel hardened to R_c30
Fluid Application:	Double pipe at a flow rate of 4 gallons per minute
Test Run Criteria:	Each test was run until .010 inches of flank wear was observed.

3.3.1.4 Test Conditions

All of the tests were performed on a Cincinnati Number 3 mill located in the Machining Research Laboratory of the Colwell Engineering Center. The test arrangement is shown in Figure 3.3-2 which illustrates the relationship of the cutting tool to the workpiece and the cutting fluid application system. The workpiece was mounted on a Kristal Instrument piezoelectric machining dynamometer which permitted evaluation of the three orthogonal forces generated while cutting (see Figure 3.3-3). The output signals from the dynamometer were recorded in analog form on a Honeywell 1858 visicorder oscillograph. The signal data were later reduced to digital values employing sensor calibration factors and measuring the signal trace deflection at the point of interest within the machining event. Tool wear measurements were ascertained utilizing a Gaertner toolmaker's microscope. In keeping with the majority of metal cutting research work, tool wear was defined as the maximum length of wear pattern observed in the tool flank face.

3.3.1.5 Milling Test Results

The milling was accomplished using a single carbide insert in a 1.68 inch diameter milling cutter body. Flank wear was measured after milling the full length of a 1.8" x 6" x 4" test block. Each test was continued until at least .010 of an inch of flank wear was observed. Linear regressions were performed on these data. A sample linear regression is displayed in Figure 3.3-4 for fluid number two. The linear regressions were plotted using ten to twenty flank wear observations, depending on the

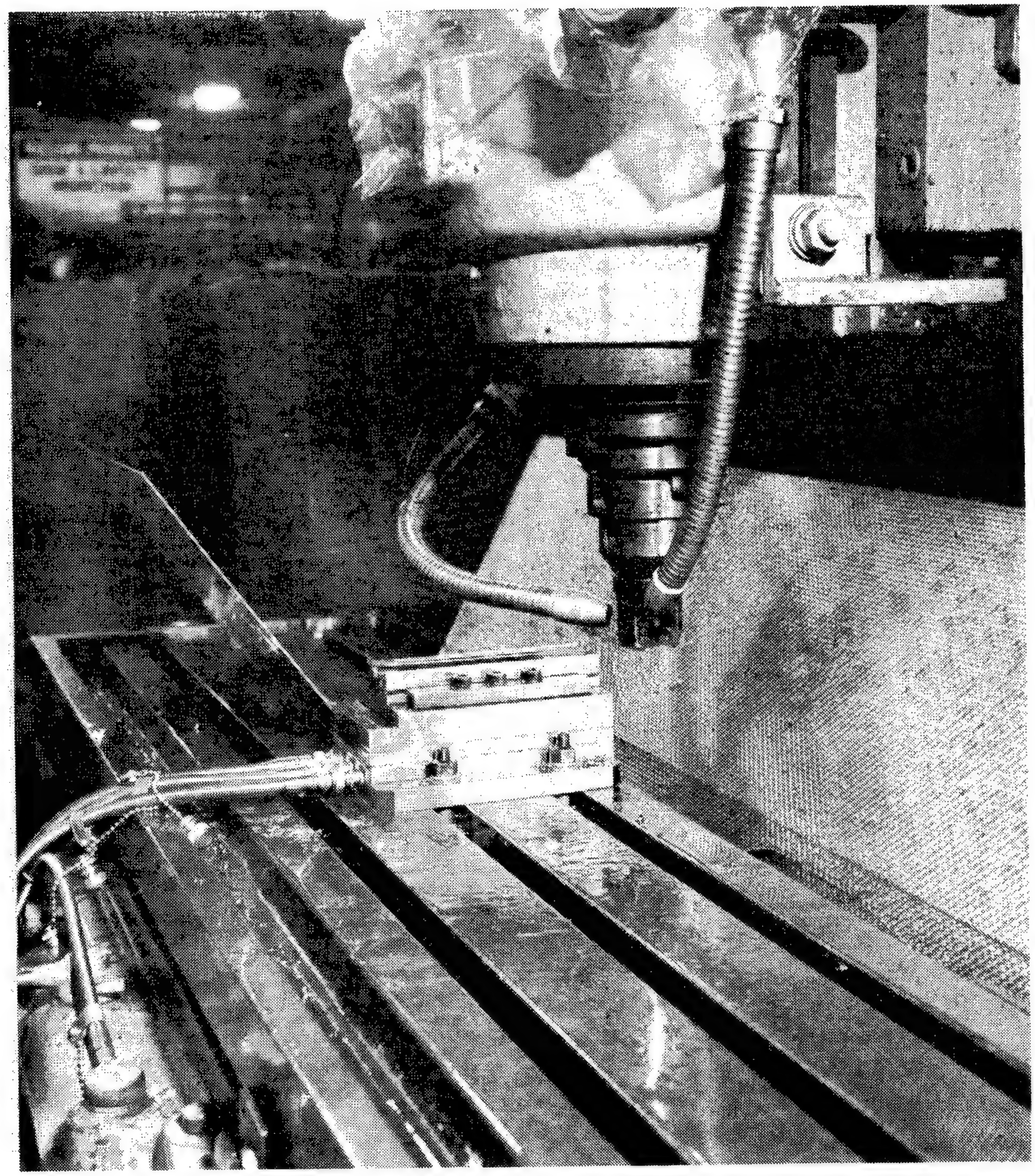


Figure 3.3-2. Photograph of the Milling Testing Arrangement.

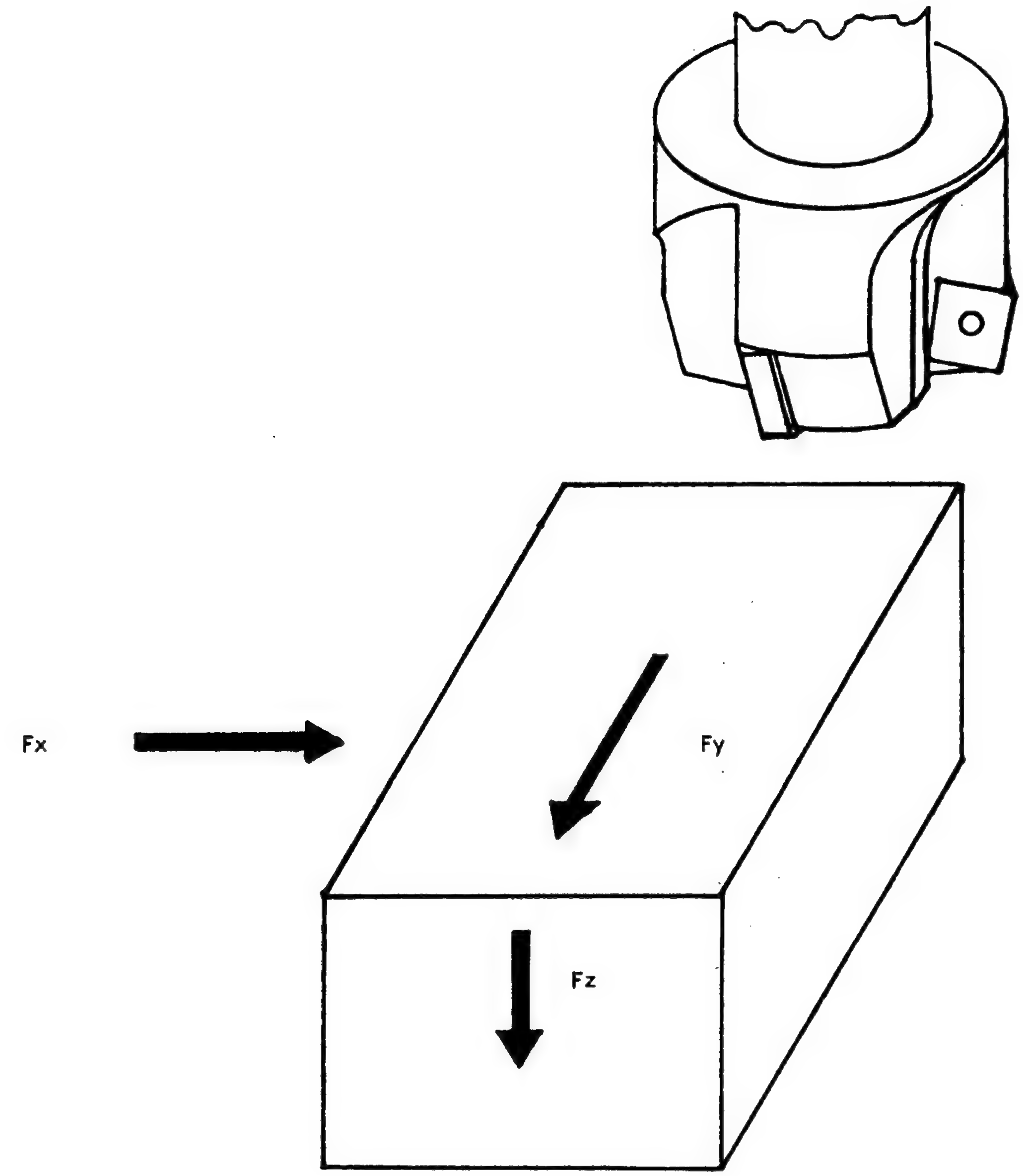


Figure 3.3-3. An Illustration of the Dynamometer Cutting Forces Measured.

1945-D

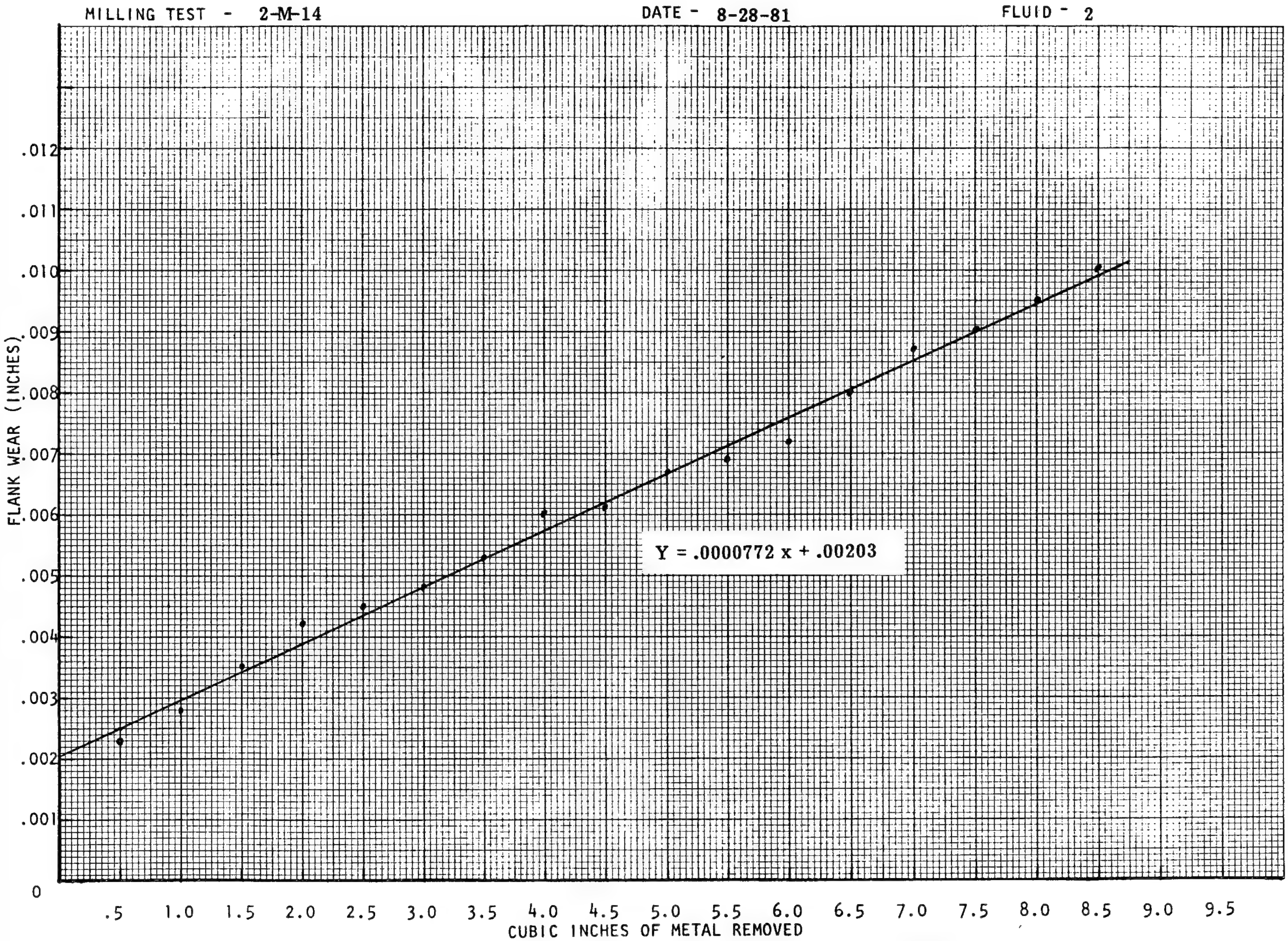


Figure 3.3-4. Sample linear regression for fluid number two.

test's tool wear rate. The average of the slopes and intercepts of each test fluid's replications were taken to calculate the amount of material removed to 0.010 inches of flank wear. Figure 3.3-4 illustrates the basic two-part form of the linear regression for fluid number two: the slope (.0000772) and the intercept (.00203).

The steady state condition which occurs after the tool's initial break-in and before catastrophic failure is described by the slope. This steady state condition takes on a linear relationship that describes the development of the tool's wear scar. The slope may be used to compare the relative performances of cutting fluids. Good cutting fluids will have a lower slope, poorer cutting fluids will have a steeper slopes.

The intercept, in general, is the extrapolation of data back to a zero point. In the case of the cutting fluid tests, the intercept represents the point just before initial tool wear contact. Initially, the tool wear process proceeds at an extremely rapid rate until the tool "breaks in". The intercept takes into account the initial condition of the cutting edge from the manufacturer as it responds to the break-in process with a slight contribution of the cutting fluid.

The total amount of metal removed (TMR) to reach .010 of an inch of flank wear was calculated for each replication of all the test fluids. The individual slopes and intercepts were average to develop a total amount of metal removed (TMR) for each test fluid. Care was taken to evaluate the R^2 value (the coefficient of determination) to insure a realistic analysis. For example, the R^2 value for the oils were approximately .6 and .8 which indicated a poor regression fit. A perfect regression line has an $R^2=1$. This meant the data had to be evaluated in an objective manner. The slopes and intercepts could not be averaged but the TMR's were averaged instead.

Force data were also collected during each six-inch milling pass. Ten to twenty data points were averaged for each test fluid, depending on the wear rates to reach .010 of an inch of flank wear. The force values were measured at the end of each six-inch milling pass. The results of these analyses are displayed in Table 3.3-2. All of these data are displayed in this table and will serve as an example of how the data analysis was performed. Photographs that typify the general wear modes of each test fluid are displayed in Figures 3.3-5 through 3.3-11. Additional tests were performed which were outside the scope of the initial cutting fluid program. These tests were run as a check to test if the test parameters were optimal milling parameters for RIA and to determine if the initially observed chipping of tools with some water base cutting fluids would continue. The tests were conducted at the following parameters:

RPM	1,300
Inches per Minute Feed Rate	6.375
SFM	572
Chip Load	.005
Doc	.050

These results are displayed in Table 3.3-3.

TABLE 3.3-2

RIA MILLING TEST RESULTS

Test #	# Pass	Fail Mode	FW	TW	Slope	b	TMR	IF_x	FF_x	AF_x	IF_y	FF_y	AF_y	IF_z	FF_z	AF_z	Remarks
31-M-1	10	Chipped	.0236	.0132	.0002333	-.00116	4.2	51	62	54.3	51	37	49.1	28	49	35.7	Tool Chipped
31-M-2	18	C	.0102	.0174	.0000756	.00188	9.0	48	62	56.6	35	42	46.9	25.5	71.0	46.9	Pock
AVG					.000154	.00036	5.2			55.4			48			41.3	
8-M-1	23	G	.0102	.0188	.0000535	.00247	11.82	47	62	54.9	34.5	41.5	37.8	21.5	80	46.7	Crater Wear Line
8-M-2	20	G	.01303	.0183	.0000662	.00183	10.4	46	65	55.1	35	45	38.3	23	75	44.6	" "
AVG					.0000598	.00215	11.0			55			38.1			45.7	
4-M-1	6	C	.0100	.0110	.000269	.000740	2.9	49.5	62	55.7	37	56.5	47.6	27.5	63	45.5	Chipping
4-M-2	8	C	.0100	.0125	.000166	.00210	4.0	47.5	62.5	54.1	34.5	53.5	41.4	26.5	56.5	36.6	"
4-M-3	11	C	.0100	.0138	.000115	.00253	5.4	48	58.5	53	33.5	39.5	37.1	23.5	54.5	37.1	"
4-M-4	11	C	.0111	.0136	.000124	.00251	5.1	48	63.5	57	34.5	71	50.8	23	88	52.5	"
4-M-5	14	C	.0100	.0193	.0000914	.00287	6.5	46.5	62	54.1	33	43.5	37.9	22	74	43.9	"
AVG					.0001276	.00179	5.4			54.8			43			43.1	
2-M-1	13	C	.0102	.0192	.0000951	.00831	6.3	27	74.5	54.2	37	46.5	41.2	42.5	64	44.9	Spike
2-M-2	14	G	.0100	.0203	.0000899	.00272	6.8	49	62.5	55.5	37	44	40.1	25.5	68	42.2	Good
2-M-3	10	Chipped	.0160	.0202	.000155	.00441	4.6	53	67	54.8	42	58	41.1	28	57	36.1	Chipped
2-M-4	13	C	.0106	.0200	.0000995	.00295	6.0	26.5	71	57.5	35.5	51	42.6	49.5	67.5	44.8	Good
2-M-5	17	C	.0098	.0216	.0000753	.00196	9.0	46	65.5	57.1	33.6	43.5	39.3	25	84	50.3	Spike
2-M-6	17	C	.0100	.0210	.0000772	.00203	8.7	54.5	65.5	57.8	38	44	39.8	24.5	81	46.5	Spike Chip
AVG.					.0000986	.00373	5.3			56.2			40.7			44.1	

TABLE 3.3-2 (Continued)

RIA MILLING TEST RESULTS

Test #	# Pass	Fail Mode	FW	TW	Slope	b	TMR	IF_x	FF_x	AF_x	IF_y	FF_y	AF_y	IF_z	FF_z	AF_z	Remarks
1-M-1	6	Chipped	.0183	.0183	.000409	-.00251	2.6	49.5	57	53.3	35	42	38.0	27.5	41	34	Chipped
1-M-2	7	Chipped	.0157	.0114	.000243	.0000857	3.4	51.5	55	54.1	37	40.5	39.3	28	44.5	33.6	"
AVG					.000326	.001212	2.9			53.7			38.7			33.8	
D-M-1	16	G	.0104	.0188	.0000900	.00154	7.9	48.5	63.5	56.2	33	45.5	37.2	22.5	66.5	44.4	Good Wear
D-M-2	17	G	.0100	.0149	.0000790	.00157	8.9	50.5	62.5	55.1	33	44.0	35.4	21.5	63.5	39.7	" "
D-M-3	17	G	.0103	.0142	.0000837	.00123	8.8	48	63	55	32.5	48	37.6	22	70	41.7	" "
AVG					.0000842	.00145	8.5			55.4			36.7			41.9	
O-M-1	20	Chipped	.0127	.0173	.0000184	.0000798	10.5	49	71	57.4	34.5	51.5	40.3	22.5	98	46.3	Pock, Tip Chipped
O-M-2	16	Chipped	.0197	.0211	.0000957	-.000508	9.2	51	79	60	33	67	41.5	23.5	120	52	" "
O-M-3	17	Chipped	.0136	.0186	.0000899	.000510	8.9	58.5	74	60	38.5	50.5	39	26	74	43.3	" "
AVG					.000068	.0000272	9.5			59.1			40.3			47.2	

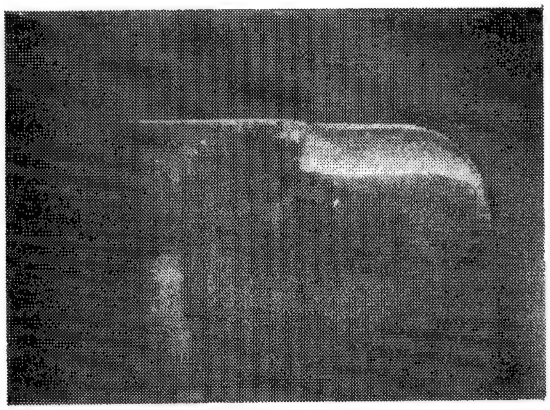
KEY FOR TABLE 3.3-2

# Pass	-	The number of times the milling cutter went across the 6" long test bar.
FW	-	End of test flank wear.
TW	-	End of test tip wear.
Slope	-	The linear regression slope.
b	-	The linear regression intercept.
TMR	-	Total metal removed at .010 flank wear.
IF_x	-	F_x force on the first pass.
FF_x	-	F_x force on the pass the tool reached .010 flank wear.
AF_x	-	Average F_x force.
IF_y	-	F_y force on the first pass.
FF_y	-	F_y force on the pass the tool reached .010 flank wear.
AF_y	-	Average F_y force.
IF_z	-	F_z force on the first pass.
FF_z	-	F_z force on the pass the tool reached .010 flank wear.
AF_z	-	Average F_z force.
G	-	Good tool wear.
C	-	Tool flank chipping with small chips.
Chipping	-	Tool flank chipping with one large chip.

CRATER

FLANK

Figure 3.3-5. Photograph of a Typical Milling Test Tool for Fluid #0.



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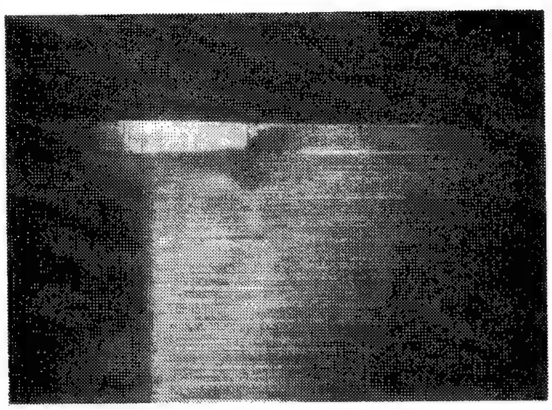


FLANK

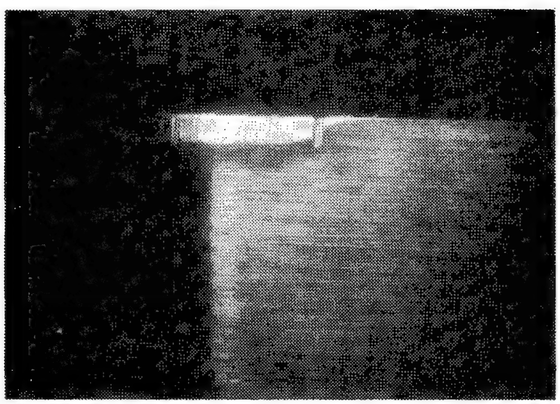
Figure 3.3-6. Photograph of a Typical Milling Test Tool for Fluid #D.

CRATER

FLANK

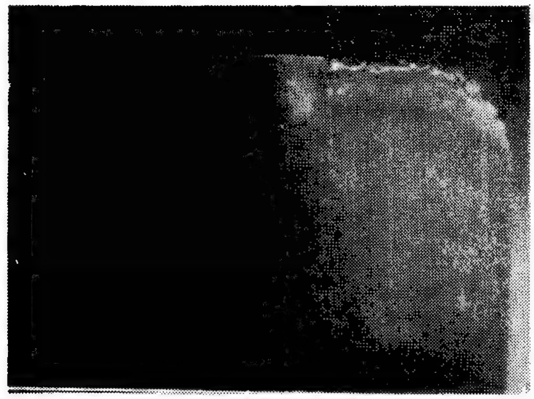
Figure 3.3-7. Photograph of a Typical Milling Test Tool for Fluid #1.

CRATER



FLANK

Figure 3.3-8. Photograph of a Typical Milling Test Tool for Fluid #2.



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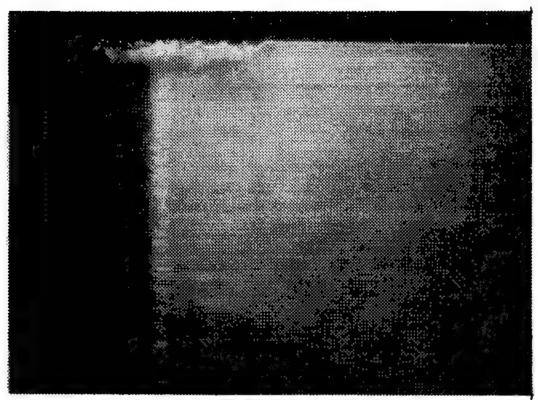
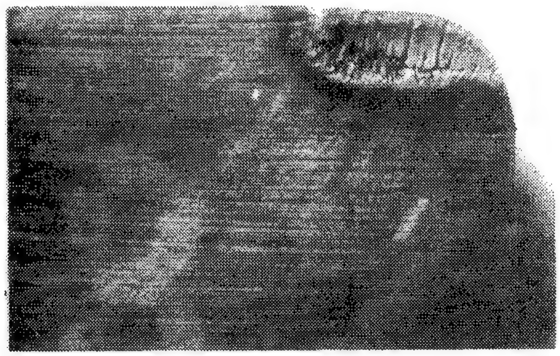


FLANK

Figure 3.3-9. Photograph of a Typical Milling Test Tool for Fluid #4.



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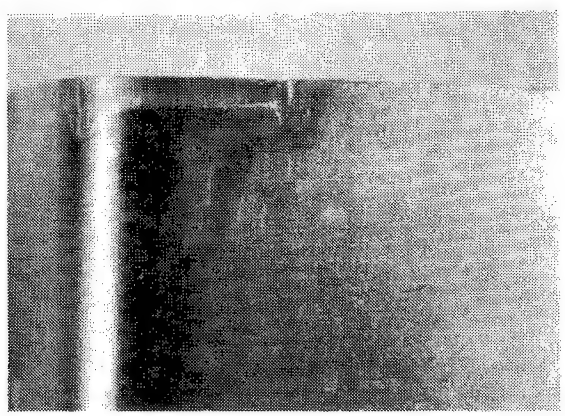
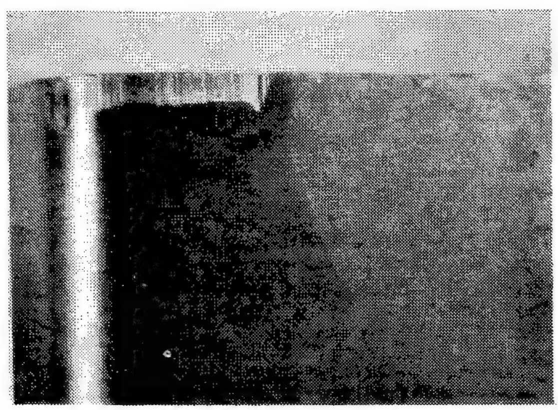


FLANK

Figure 3.3-10. Photograph of a Typical Milling Test Tool for Fluid #8.

CRATER



FLANK

Figure 3.3-11. Photograph of a Typical Milling Test Tool for Fluid #31.

TABLE 3.3-3

RIA EXTRA MILLING TEST RESULTS

Test #	# Pass	Fail Mode	FW	TW	Slope	b	TMR	IF_x	FF_x	AF_x	IF_y	FF_y	AF_y	IF_z	FF_z	AF_z	Remarks
D-MF-1	15	G	.0105	.0211	.000104	.00114	7.2	36.5	45.5	40.5	22	25	23.4	18.5	46.5	32.3	Good Wear
D-MF-2	14	G	.0105	.0215	.000110	.00112	6.8	35	45.5	40.3	21	24.5	23.6	15.5	45	32.1	" "
AVG					.000107	.00113	7.0			40.4			23.5			32.2	
1-MF-1	2	Chipped	.0114	.0066	.00156	-.00733	1.0	36.5	36.5	36.5	23	23.5	23.3	18.5	20.5	19.7	Chipped
1-MF-2	6	Chipped	.0100	.0116	.000190	.000687	4.1	36	39	37.5	24	24.5	24.6	18.5	29.5	23.6	"
AVG					.000875	-.00332	1.3			37			24			21.7	
2-MF-1	9	Chipped	.0268	.0164	.000308*	-.00245	3.4	36.5	41	38.9	23.5	27	25.1	17.5	39	26.6	Chipped
2-MF-2	9	Chipped	.0119	.0171	.000145*	.000407	5.6	36	40	37.9	23	26.5	24.4	17	42.5	28.2	"
AVG					.000227	-.00102	4.08			38			24.8			27.4	
4-MF-1	9	Chipped	.140	.0134	.000213*	-.000597	4.2	35.5	46	38.7	22	42	26.3	17.5	39.5	27.6	Chipped
4-MF-2	10	Chipped	.011	.0146	.000159*	-.000621	5.5	35.5	45	39.6	22.5	39.5	27.9	17.5	43.5	29.4	"
AVG					.000186	-.000609	4.8			39.2			27.1			28.5	

* R^2 value indicates poor line fit.

KEY FOR TABLE 3.3-3

# Pass	-	The number of times the milling cutter went across the 6" long test bar.
FW	-	End of test flank wear.
TW	-	End of test tip wear.
Slope	-	The linear regression slope.
b	-	The linear regression intercept.
TMR	-	Total metal removed at .010 flank wear.
IF_x	-	F_x force on the first pass.
FF_x	-	F_x force on the pass the tool reached .010 flank wear.
AF_x	-	Average F_x force.
IF_y	-	F_y force on the first pass.
FF_y	-	F_y force on the pass the tool reached .010 flank wear.
AF_y	-	Average F_y force.
IF_z	-	F_z force on the first pass.
FF_z	-	F_z force on the pass the tool reached .010 flank wear.
AF_z	-	Average F_z force.
G	-	Good tool wear.
C	-	Tool flank chipping with small chips.
Chipping	-	Tool flank chipping with one large chip.

3.3.1.6 Milling Test Conclusions

The data and photographs indicate that the test fluids performed quite differently from one another. Two histogram graphs were computed from data displayed in Table 3.3-2. The first graph is presented in Figure 3.3-12 and shows the cubic inches of material removed when the cutting tool used with that fluid reached .010 of an inch of flank wear. Also, each cutting fluid was compared by percentage of increased tool life to test fluid number one, which had the lowest performance of the fluids tested (see Figure 3.3-13).

The data analysis indicates that the milling performed at RIA is a lubrication sensitive process. This means the greater the lubrication property of the cutting fluid used, the more material a cutting tool will remove prior to failure. The semi-synthetic fluid #8 containing a special formulation of polar fatty acids and a special wetting agent has proven to be the superior cutting fluid. This is due to the fluid's ability to maintain lubrication between the material/tool interface. The polar attraction of the fluid to the material being machined and another proprietary characteristic of this fluid accomplishes this. The polar attraction acts like a magnet which pulls the fluid to the freshly exposed metal.

Milling at RIA seems to be adversely affected by the rapid heat abstraction properties of some common water based cutting fluids. Chipping was observed on cutting tool inserts on all tests used with medium duty (fluid #1) and heavy duty synthetic fluids (fluid #4). This chipping was caused by thermal fatigue due to the milling process itself and the high rate of cooling characteristic of a synthetic cutting fluid. As the cutting tool's insert enters the workpiece, the resulting machining process generates heat which is partially absorbed by the insert. When the insert leaves the cut it is quenched or cooled very rapidly by the cutting fluid. This accelerated cooling characteristic of a synthetic cutting fluid produces a thermal shock condition throughout the insert. Such continual heating and rapid cooling which characterizes the milling process continues many times a second as a milling insert passes through the workpiece material. The continual heating and rapid cooling causes the insert edge to crumble or chip apart (see Figures 3.3-7 and 3.3-9). Chipping was the main mode of milling tool failure observed at RIA (see Phase II Third Quarterly Report, July, 1981).

Milling with an oil did not have as severe chipping as with the synthetic cutting fluids. However, extreme abrasive tip wear was observed. The tip would wear down and cause the tool's flank to flake away (see SEM photograph in Figure 3.3-14 taken after 10.5 cubic inches of metal were removed.) Note that the crater area seems to be worn away. X-ray energy dispersive analysis indicated a lack of cobalt was found on the surface of these indentations, which would suggest that the sulfochlorinated oil attacked the tool's cobalt binder (see X-ray energy dispersive analysis, Figure 3.3-15). This excessive tip wear caused by a lack of proper lubrication. An overactive product effectively corrodes the tool, while low fortification level fails to protect the tool edge. Examining the SEM photograph for test fluid #8 (Figure 3.3-16 taken after 11.82 cubic inches of metal were removed) shows a uniform wear pattern. This is due to this fluid's wetting ability. The lubrication is able to reach the tip portion of the tool. Notice that test tool #8 also has a slight valley above the normal crater area. Again, this may be caused by cobalt sulfidation attack (see X-ray energy dispersive analysis on Figure 3.3-17). Examination of fluid #4's SEM (Figure 3.3-18 taken after 5.1 cubic inches of metal

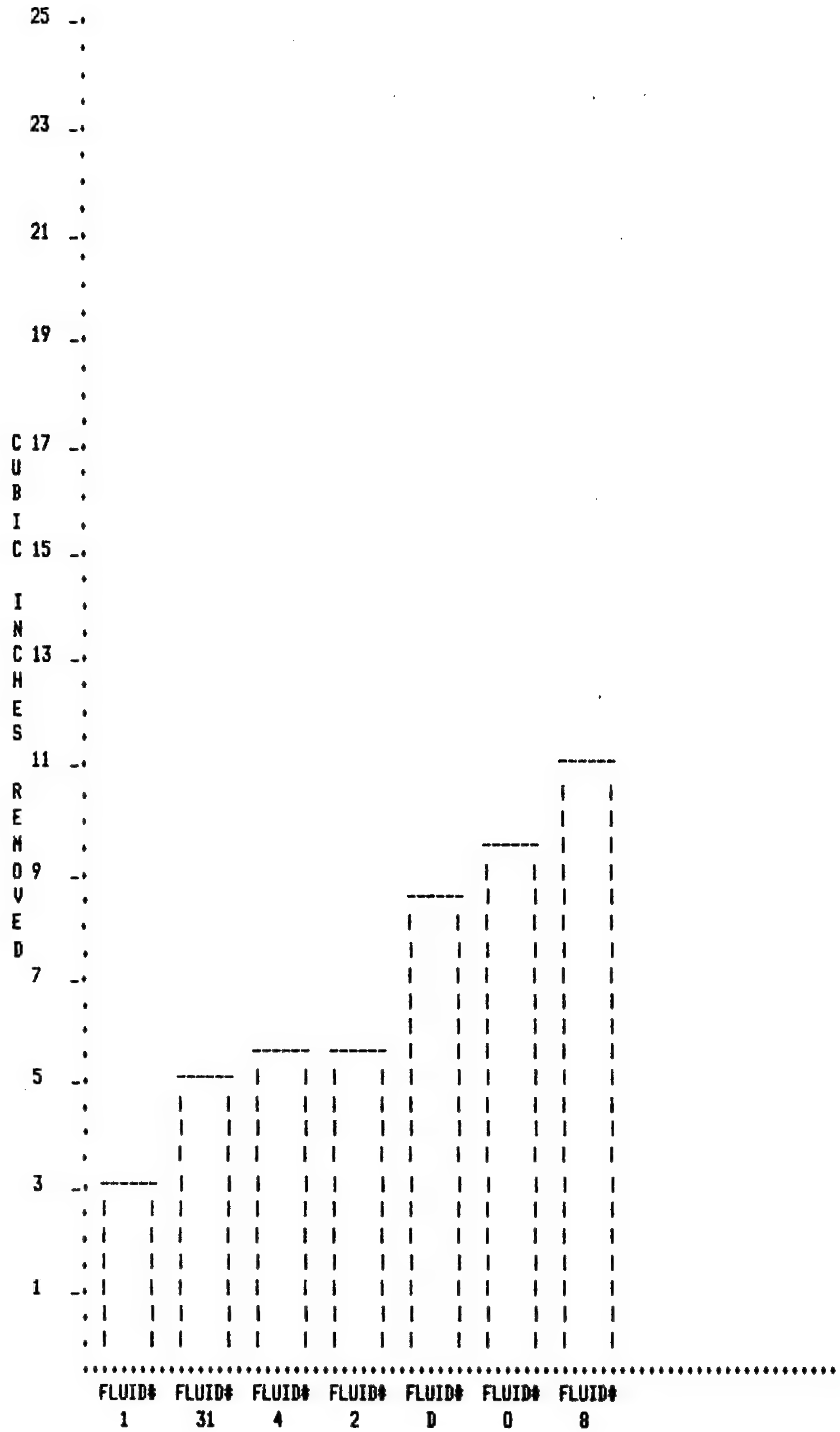


Figure 3.3-12. **Cubic Inches of Metal Removed to .010" Flank Wear vs. Milling Fluids Tested.**

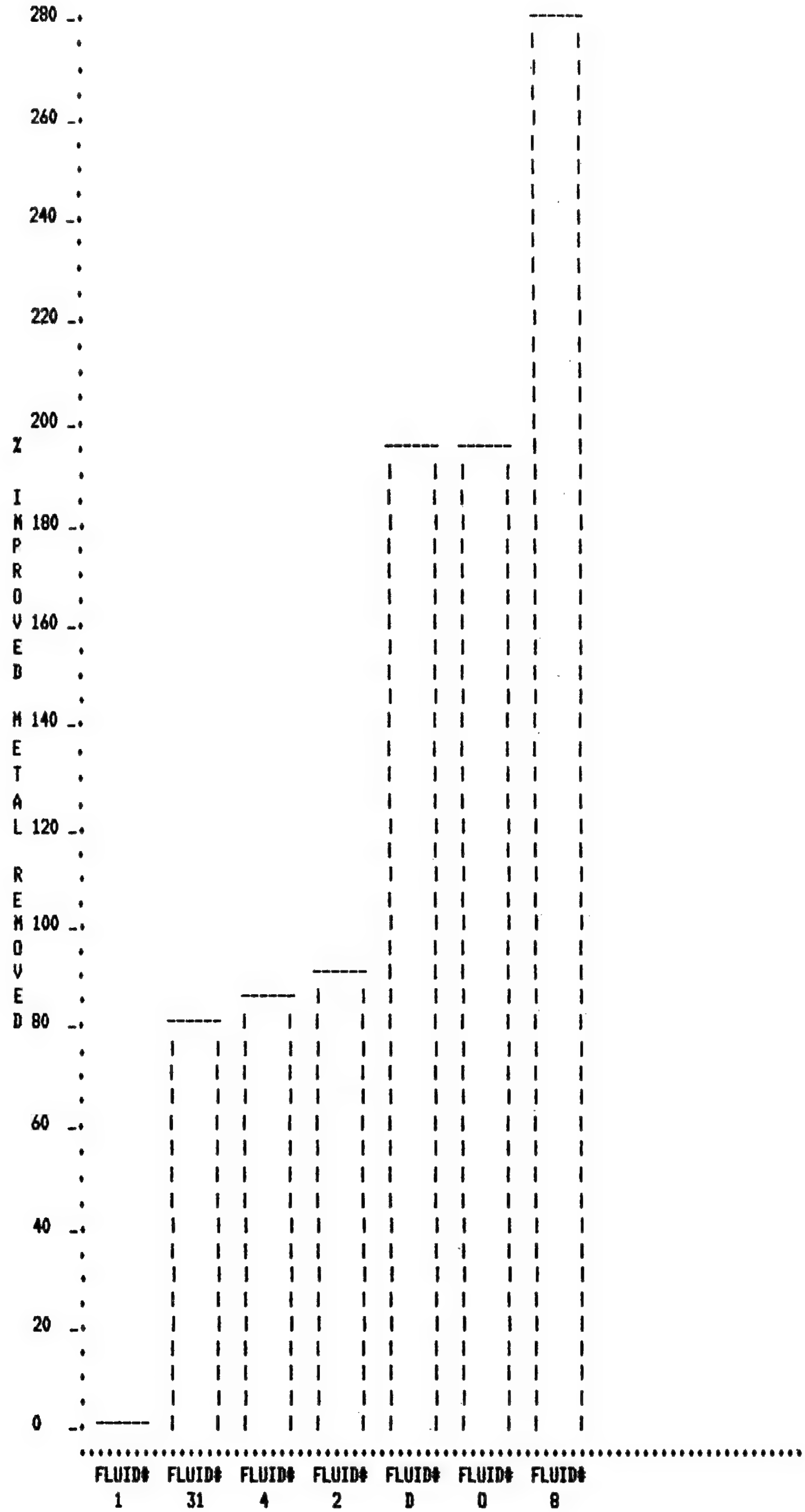


Figure 3.3-13. Percent of Increased Tool Life Compared to Test Fluid #1.

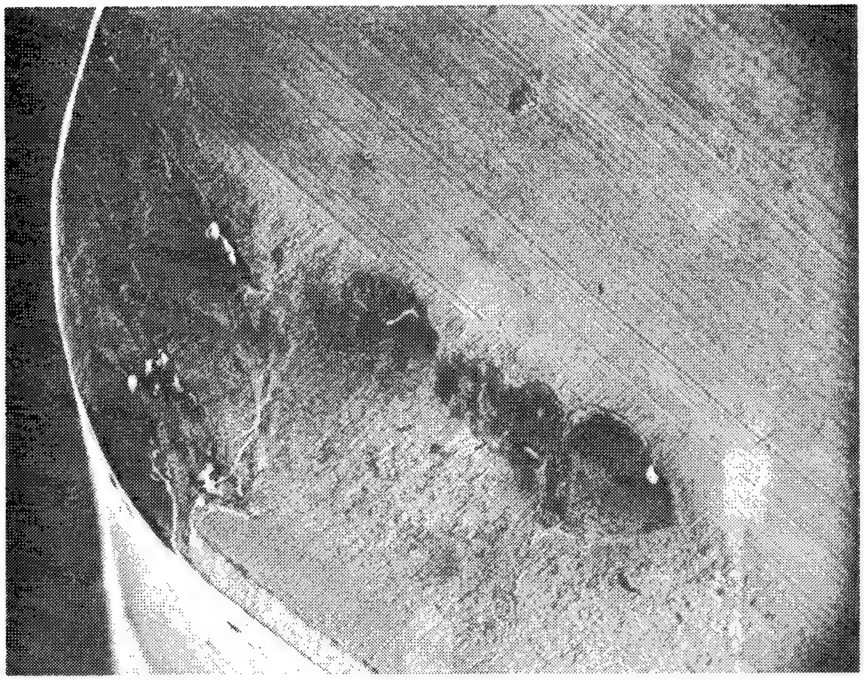


Figure 3.3-14. SEM Photograph (80X) of Fluid O's Milling Test Tool O-M-1 After Machining 10.5 Cubic Inches of Material.

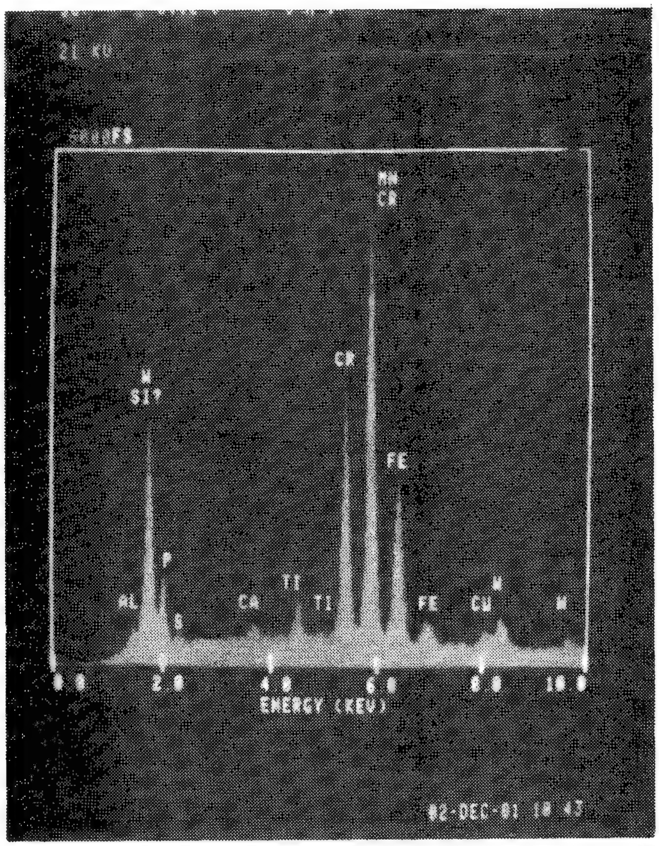


Figure 3.3-15. X-ray Energy Dispersive Analysis of Fluid O's Milling Test Tool O-M-1.

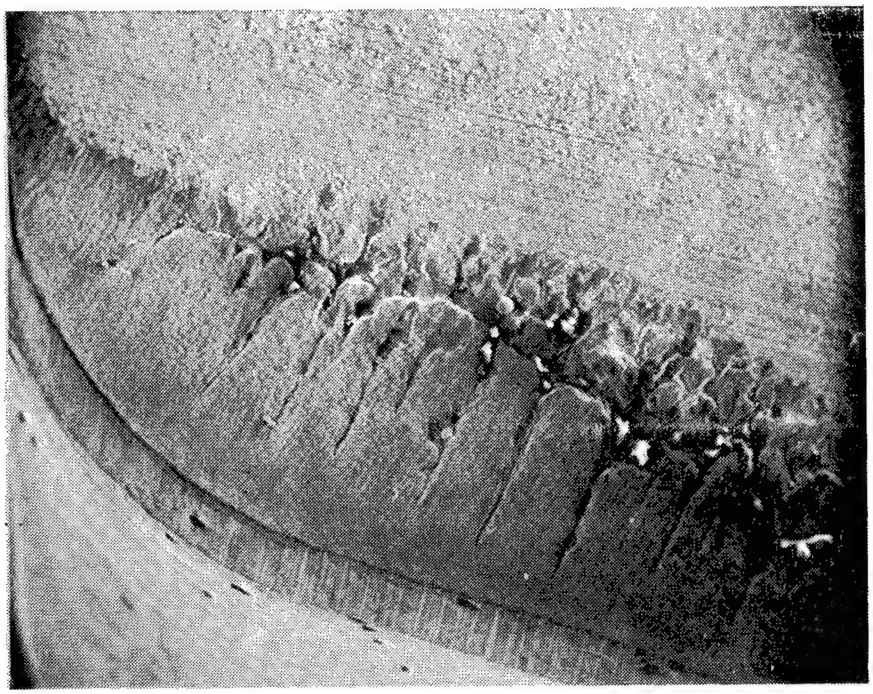


Figure 3.3-16. SEM Photograph (80X) of Fluid 8's Milling Test Tool 8-M-1 After Machining 11.82 Cubic Inches of Material.

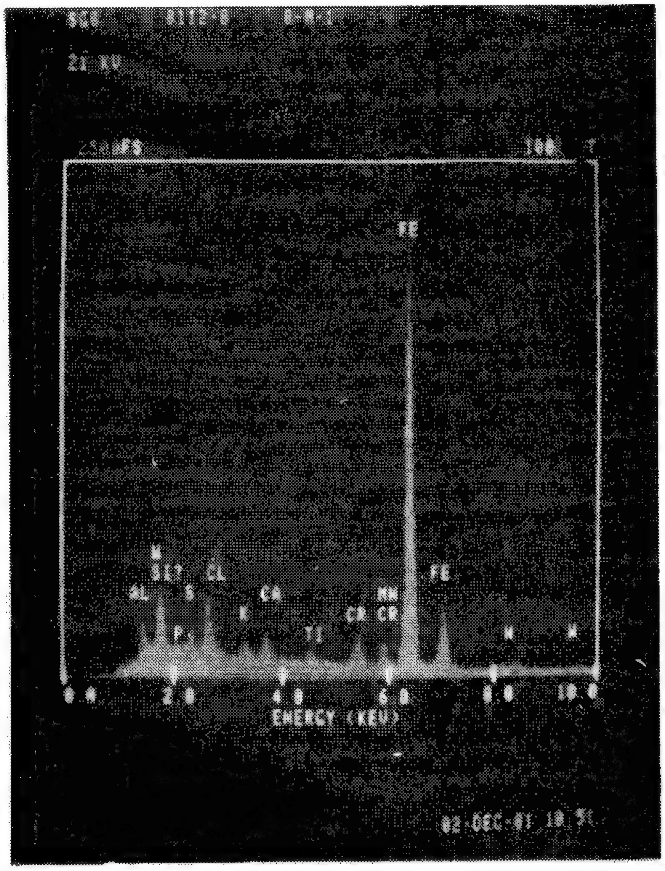


Figure 3.3-17. X-ray Energy Dispersive Analysis of Fluid #8's Milling Test Tool 8-M-1.

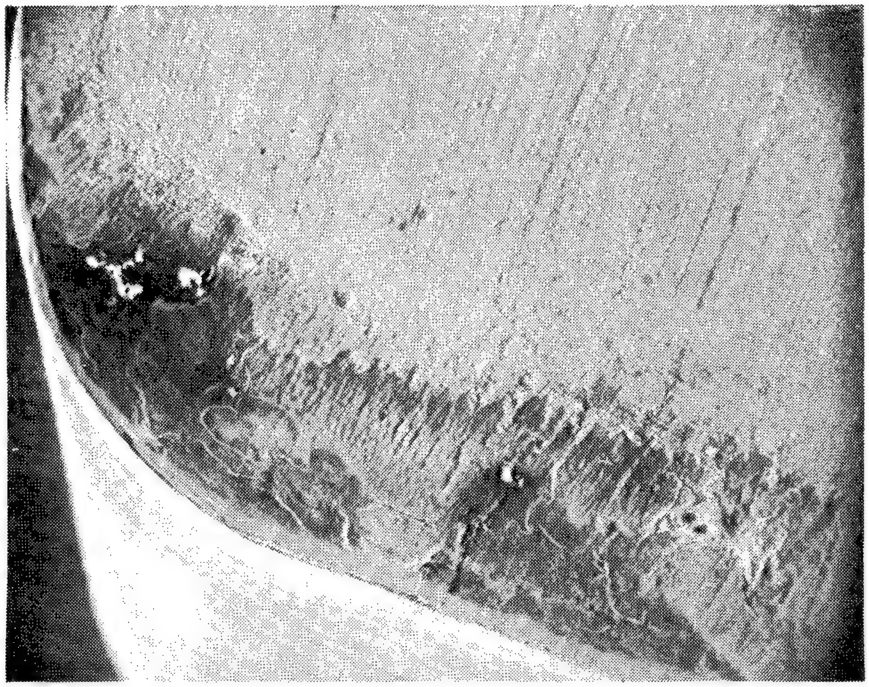


Figure 3.3-18. SEM Photograph (76X) of Fluid #4's Milling Test Tool 4-M-4 After Machining 5.1 Cubic Inches of Material.

were removed) further supports this concept. Even though the test tool wore faster due to chipping, the wetting action of the fluid did penetrate to the tip. Test fluid #4 is a heavy duty, high lubricity full synthetic fluid with some wetting ability.

Inserts that were used in dry machining (without a cutting fluid) performed better than those that had the thermal fatigue problem brought on by intermittent extreme cooling such as the synthetic fluids #1 and #4. Note that the inserts that machined dry did not experience any chipping (see Figure 3.3-5). This supports the hypothesis that thermal shock caused the chipping on some of the inserts used with water-soluble cutting fluids.

The 50 gallon sump cost for each of these fluids are displayed in Figure 3.3-19. The fluid that displayed the highest performance and third lowest sump cost is fluid #8 with a 50 gallon sump cost of $14.42. The fluid that cost the least was the next to last performer, fluid #31, with a $7.25 fifty gallon sump cost. The 111% performance increase of fluid #8 over fluid #31 clearly makes the general category of high lubrication, high wetting, and medium cooling, which fluid #8 falls in, the logical selection for milling at RIA. The category of high cooling and low lubrication which fluid #1 falls in is the worst category for milling 4100 series material at RIA machining parameters.

The additional tests that were performed at higher SFM's and feeds which were displayed in Table 3.3-3 confirm that the typical RIA parameters selected for testing were not the cause of chipping. However, the excellent test results at these parameters, at the .050 of an inch depth of cut, indicate that these parameters should be tried at RIA. The data show potential for increased productivity.

3.3.2 Turning

The turning section will review the highlights of the manufacturing survey taken at RIA, describe Machining Technology's testing procedures and relate the results of these tests. Additional information on the training process and a detailed discussion of the basic concepts of turning may be reviewed in Section 3.5 of Establishment of a Cutting Fluid Control System (Phase I). These topics will be presented in the following subsections: Review of RIA turning and boring survey, turning cutting fluid test selection, turning test design, Machining Technology's test conditions, turning test results and conclusions.

3.3.2.1 RIA Turning and Boring Survey

Seventy-five percent of the observations for turning and boring exhibited either extreme wear due to chipping or extreme wear due to cratering without evidence of flank wear or built-up edge (BUE) effects (see Table 3.1-3 in RIA Phase II Final Report). This observation indicates that the desired balanced wear between cratering and flank wear is not being achieved. Examples of the observed crater wear for turning may be viewed in Figure 3.1-5 in the Phase I report. The scanning electron microscope (SEM) photomicrographs indicate excessive crater wear and minimal flank wear are already evident.

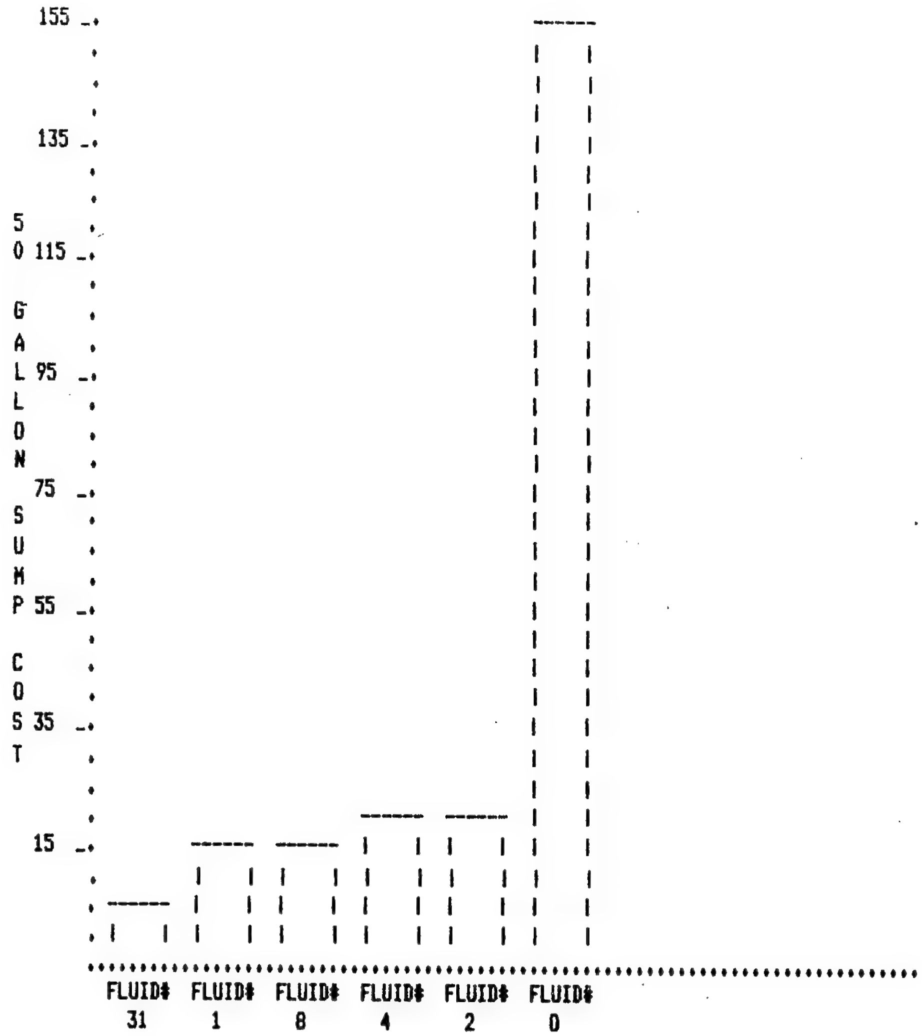


Figure 3.3-19. Price to Fill a 50 Gallon Sump vs. Milling Fluids Tested.

On-site observations indicated that the present methods for physical fluid application appeared to be adequate. Sufficient cutting speeds for carbide tools, 300-600 SFM, for the most part were achieved which essentially eliminated the possibility for the built-up edge mode of wear. The exceptions were when older low-speed machines were utilized. In some cases tool rigidity or using too hard of a carbide grade may have also contributed to initiate chipping. Insufficient concentration of the present cutting fluid or the utilization of an inadequate cutting fluid has the highest probability of being the primary cause of premature tool failure by the undesirable chipping mode.

A summary of the turning and boring machining data collected at RIA is displayed in Table 3.2-1 and Table 3.2-2 in the Phase I report. This information was used to select the test parameters used.

3.3.2.2 Turning Cutting Fluid Test Selection

All three generic types of cutting fluids were tested and compared to a base cutting fluid without E.P. additives. These fluids with manufacturer classification, test number and associated 50 gallon sump costs are displayed in Table 3.3-4. The base cutting fluid was number three and was the same base fluid used in the Phase I test program. All of the test fluids except #3 and #33 were considered by the manufacturers to be medium or heavy duty cutting fluids. Fluid #2 was selected for testing because it is currently being used at RIA. Fluid #1 was selected because it was shown to be a good grinding and turning fluid in the Phase I testing. The combined effects of sulfur and chlorine would be observed during the testing of fluid #34. Fluid #7 was tested because it contained sulfur as an E.P. additive. An emulsion containing no E.P. additives but a wetting agent is fluid #33. Three heavy duty full synthetic fluids with different properties were chosen. Fluid #32 has chlorine as an E.P. lubricant. Heavy duty lubrication properties, an effective wetting action and an oily residue characterize test fluid #4. Test fluid #15 has proprietary lubricative additives. An extreme wetting ability is contained in test fluid #8 along with fatty acids.

3.3.2.3 Turning Test Design

The boring test was combined with the turning test due to the similarities of both processes. All of the Phase II turning tests were conducted at the severest turning parameters used at RIA. However, unlike the Phase I tests, the Phase II tests were conducted with a 90% martensitic structured R_c30 material. These tests simulated the worst machining conditions that RIA could encounter with its 4100 material specifications.

Tooling:	Kennametal TNMA-543E, K21, uncoated carbide insets
SFM:	800 surface feet per minute (SFM) and 450 SFM
Feed Rate:	.0138 inches per revolution (IPR) and .0260 IPR
Depth of Cut:	.050 inches
Material:	4140 steel hardened to R_c30
Fluid Application:	Single pipe at a flow rate of 4 gallons per minute
Test Run Length Criteria:	Each test was continued until the minimum of .020 flank wear was observed for the 800 SFM tests and .010

TABLE 3.3-4

TURNING FLUIDS SELECTED FOR TESTING

Fluid Number	Fluid	Manufacturer	Strength	Type	Cl	S	Others	50 Gal Sump Cost
1	Cimfree 238	Cincinnati Milacron	MD	FS			++	$13.61
2	Trimsol	Master Chemical	MD	E	C			19.62
3	550 P	Van Straaten	MD	SS				11.48
4	Cimcool 400	Cincinnati Milacron	HD	FS			+++	19.28
7	Gulf Cut HD	Gulf Oil	HD	E		S		9.88
8	DASCOOL 502	Stuart Oil	HD	SS			+++	14.42
15	Lubricoolant 925	DuBois	MD	FS			++	22.35
32	Trim HD	Master Chemical	HD	FS	C			15.71
33	Trim LC	Master Chemical	LD	E			+	17.88
34	811	Norton	MD	E	C	S		21.00

Key:
LD = Light Duty
MD = Medium Duty
HD = Heavy Duty

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic

Cl = Chlorine
S = Sulfur
+ = Other

3.3.2.4 Test Conditions

All tests were performed on a Mori Seike SL3 numerical controlled lathe located in the machining research laboratory of the Colwell Engineering Center. The testing arrangement is shown in Figure 3.3-20, which illustrates the relationships of the cutting tool to the workpiece and the cutting fluid application system. The tool holder was mounted on a Kristal Instrument, Piezoelectric Machining Dynamometer, which permitted evaluation of the three orthogonal forces generated while cutting (see Figure 3.3-21). The power was monitored by a Valenite power monitor connected directly to the spindle motor of the lathe. The output signals from the power monitor and the dynamometer were recorded in analog form on a Honeywell 1858 Visicorder Oscillograph. The signal data were later reduced to digital values employing sensor calibration factors and measuring the signal trace deflection at the point of interest within the machining event. Tool wear measurements were ascertained off-line utilizing a Gaertner toolmaker's microscope. In keeping with the majority of metal cutting research work, tool wear was defined as the maximum length of the wear pattern observed on the tool flank face.

3.3.2.5 Turning Test Results

Flank wear was measured for each cutting fluid evaluation after turning successive increments of one-half inch in the X-direction. This procedure was continued until at least .020 of an inch of flank wear was measured. Initially the tests were run to .030 inch flank wear. However, some fluids performed so well that in order to run these tests to .030 inch of flank wear it would require a prohibitive amount of test time and material. Hence, the tests were terminated after sufficient data points were taken (usually 15) to develop an accurate tool wear rate.

These data were taken and a linear regression analysis was performed on them. A sample linear regression for fluid number two is displayed in Figure 3.3-22. The majority of the linear regressions were calculated utilizing fifteen data points.

Understanding what the linear regression equation represents and how it is formulated is important when interpreting the test results. Figure 3.3-22 shows the basic two-part form of the linear regression: the slope (.00491) and the intercept (.00340).

The steady state condition which occurs after the tool's initial "break in" and before catastrophic failure is described by the slope. This steady state condition takes on a linear relationship that describes the development of the tool's wear scar. The slope may be used to compare the relative performances of cutting fluids. Good cutting fluids will have a lower slope, while poorer cutting fluids will have steeper slopes.

The intercept value is not a direct physical measurement but it in effect represents the cumulative results of rapid tool wear which occurs on a new tool edge during the initial stages of a cut. This value is obtained by merely extrapolating the steady-state wear rate back to its intersection of the flank wear axis at zero cutting time. Variations observed in the values of this intercept are primarily a function of

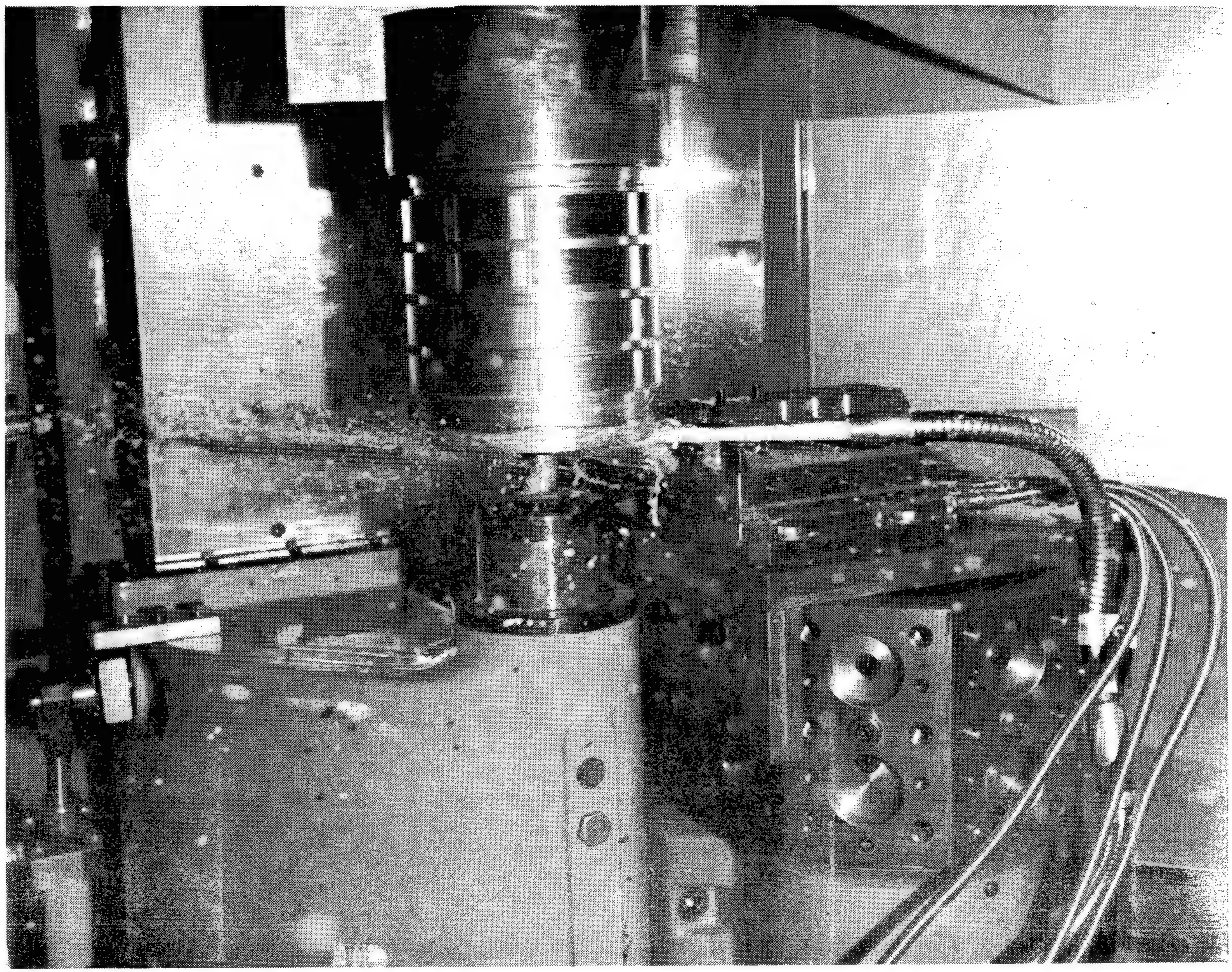


Figure 3.3-20. Photograph of the Turning Testing Arrangement.

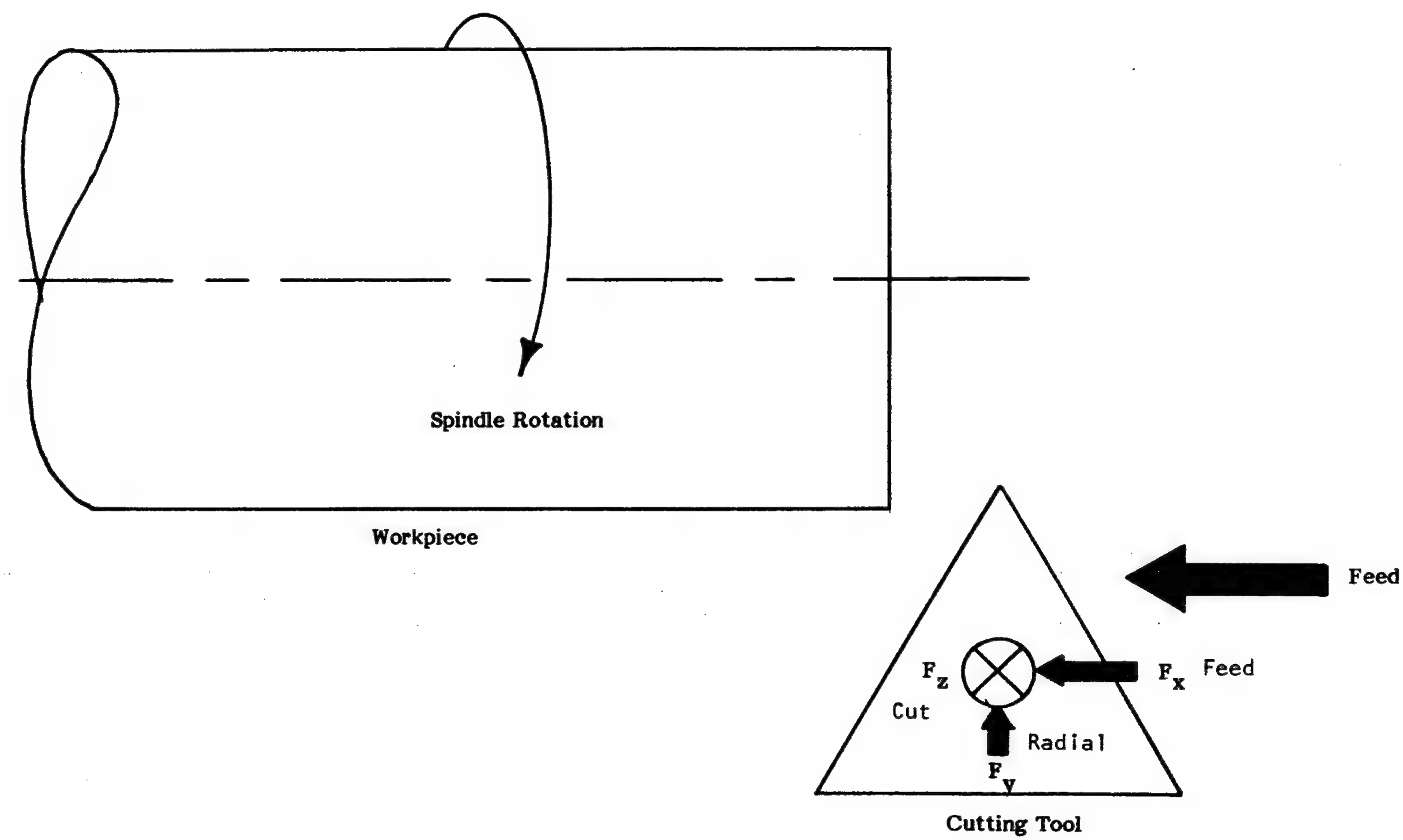


Figure 3.3-21. Dynamometer Force Configuration.

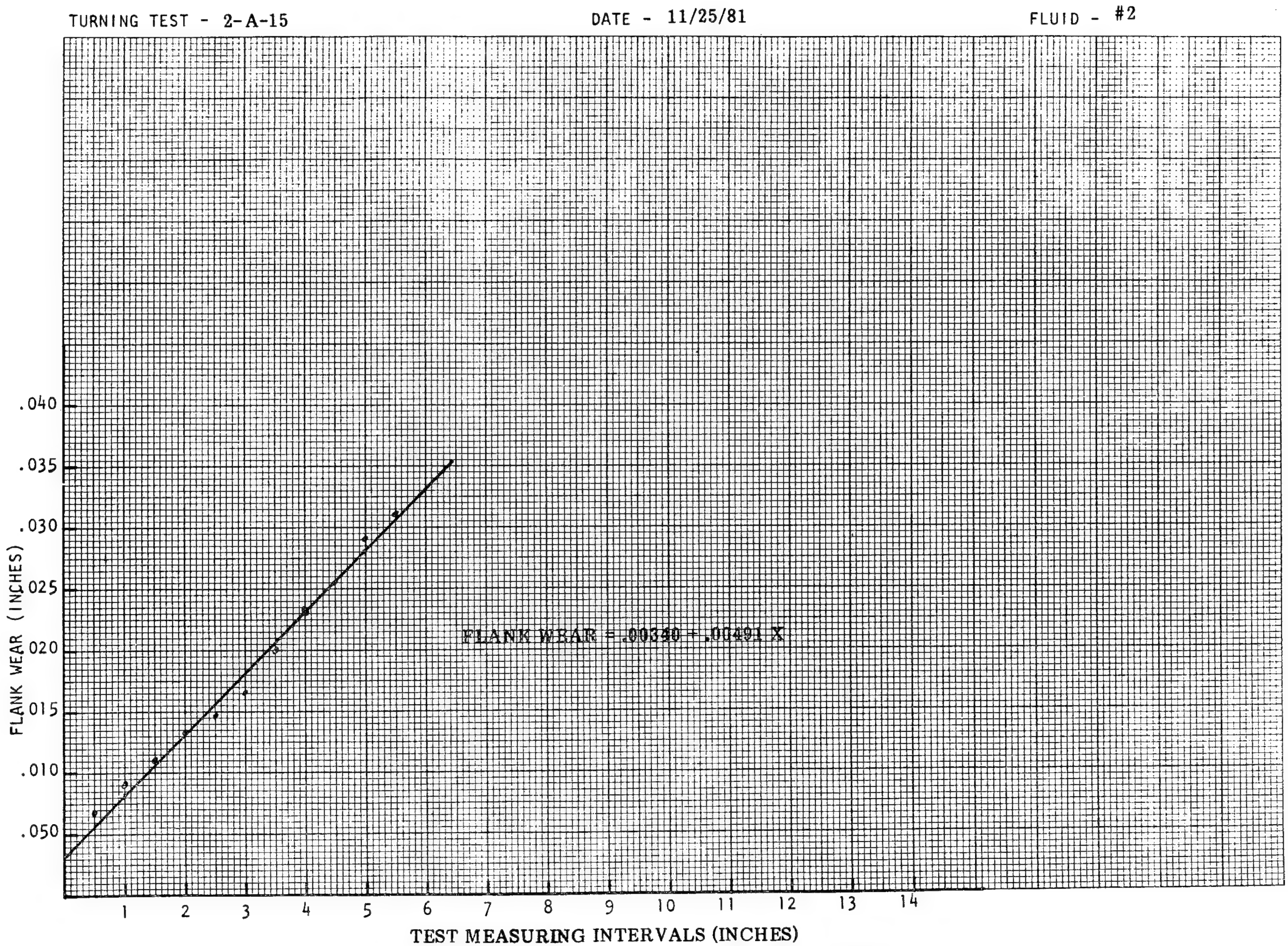


Figure 3.3-22. Sample Linear Regression for Test Fluid #2.

variations in individual cutting edges. There may be minor contributions to this break-in process attributable to the cutting fluid, but the major effects are primarily related to the cutting tool.

The total amount of metal removed (TMR) to reach .030 of an inch of flank wear was calculated for each replication of all test fluids. The average of three replications for each test fluid was performed. In order to normalize the data, all of the test data was extrapolated to .030 inch flank wear using linear regression techniques. This was feasible because all of the R^2 values (coefficient of determination) were greater than .98. A perfect linear regression fit has an R^2 value of 1. The individual slopes and intercepts were averaged along with the total amount of metal removed (TMR) for each test fluid.

Force and power data was also collected during each one-half inch X-direction turning cut. Ten to fifteen data points were averaged for each test fluid depending on when the tool reached .030 of an inch of flank wear. The power and force values were measured at the end of each one-half inch X-direction turning cut.

The results of these analyses are displayed in Table 3.3-5. Also, no excessive flank wear, cratering or chipping was observed during the tests or the SEM evaluations. Photographs that are representative of the general wear modes of each test fluid are presented in Figures 3.3-23 through 3.3-32.

3.3.2.6 Turning Conclusions

Two histogram graphs were computed from the data displayed in Table 3.3-5. The first graph is displayed in Figure 3.3-33 and shows the cubic inches of material removed before the cutting tool used with that fluid reached .030 of an inch of flank wear. Also, each cutting fluid was compared by percentage of increased tool life to test fluid number three. This graph is displayed in Figure 3.3-34. Note that these graphs used average TMR's of all of a particular fluid's replications.

The test results indicated that some fluids performed about forty to fifty percent better than others. After examining all the test fluids that did extremely well, they all had one property in common. Each of these fluids had heat reducing properties. This would suggest that the turning process is a temperature sensitive process.

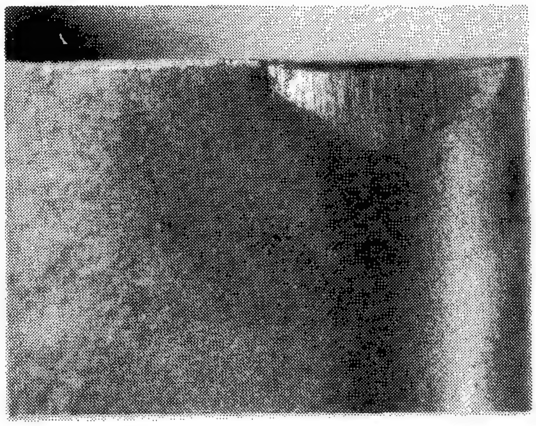
Each high performing fluid reduced heat through some characteristic process. Some fluids used E.P. lubrication such as sulphur in test fluid #7. The sulfur would reduce the friction between the cutting tool, chip and workpiece. This would lower the overall temperature of the system. Other fluids used extreme cooling as with test fluid #1. The cooling properties of the fluid would reduce the temperature of the cutting process. One fluid (fluid #8) used lubrication, cooling with an extremely good wetting action. The highest performing fluid (fluid #4) used a combination of high cooling, some wetting action and heavy duty lubrication properties.

In summary, all of the test fluids performed very closely to one another. Only fluid numbers 3, 32 and 34 were less efficient than the rest of the group. Light duty semi-synthetic fluid number 3 performed poorly because it was selected as a testing

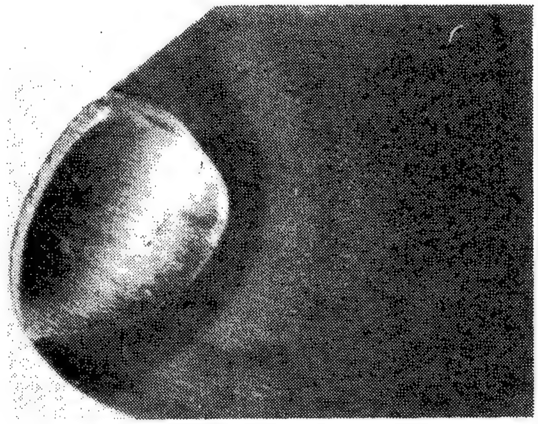
TABLE 3.3-5

RIA TURNING TEST RESULTS FOR 800 SFM

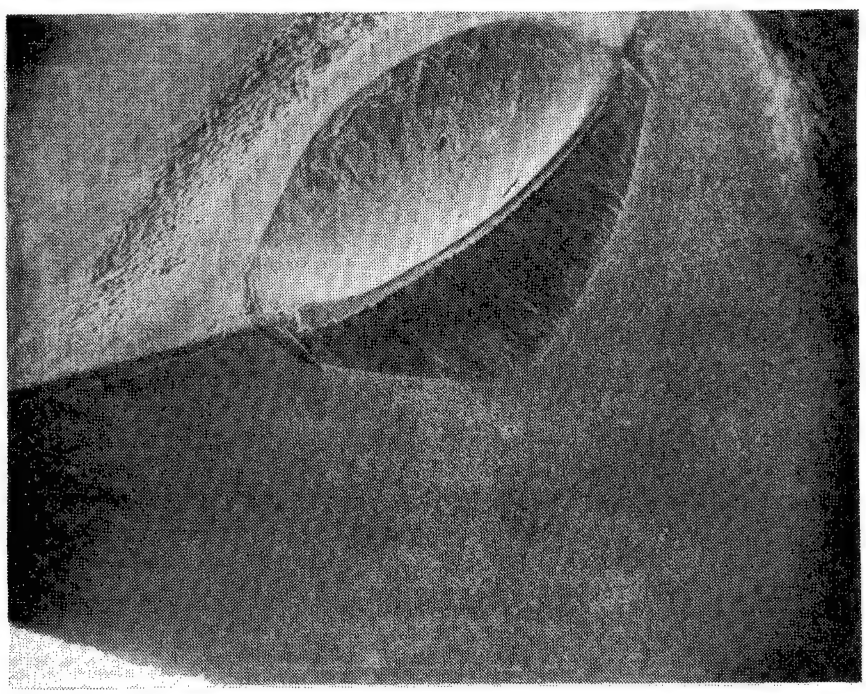
Test Fluid	TMR	Slope	Intercept	Average Cut Force	Average Radial Force	Average Feed Force	Avg. Power
1	6.9	.00239	.00682	117	67	65	11
2	5.9	.00258	.00586	120	70	68	12.2
3	4.9	.00325	.00675	126	73	74	12
4	7.6	.00226	.00647	122	64	67	11.2
7	7.0	.00230	.00799	123	67	68	11.3
8	6.5	.00241	.00559	120	67	67	11.9
15	6.7	.00252	.00634	122	65	68	11.5
32	6.1	.00283	.00604	124	68	70	11.5
33	6.4	.00234	.00697	120	67	68	11.6
34	5.2	.00341	.00610	123	69	71	11.1



FLANK

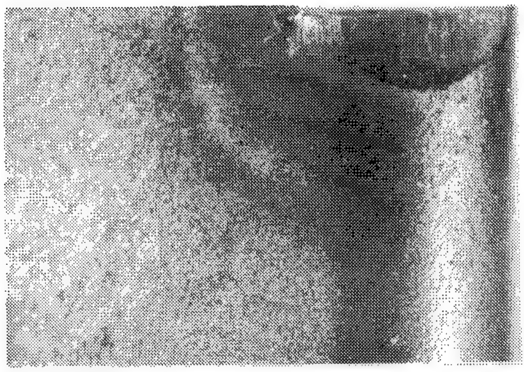


CRATER



SEM (30X)

Figure 3.3-23. Photograph of a Typical Turning Test Tool for Fluid #1.



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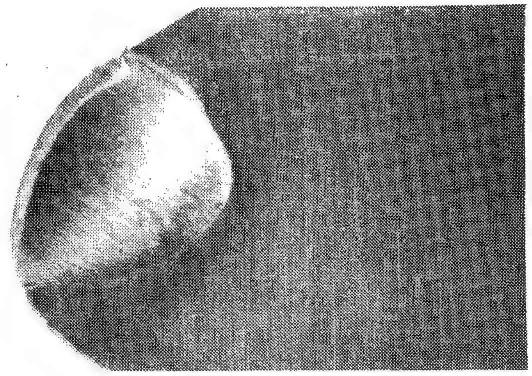

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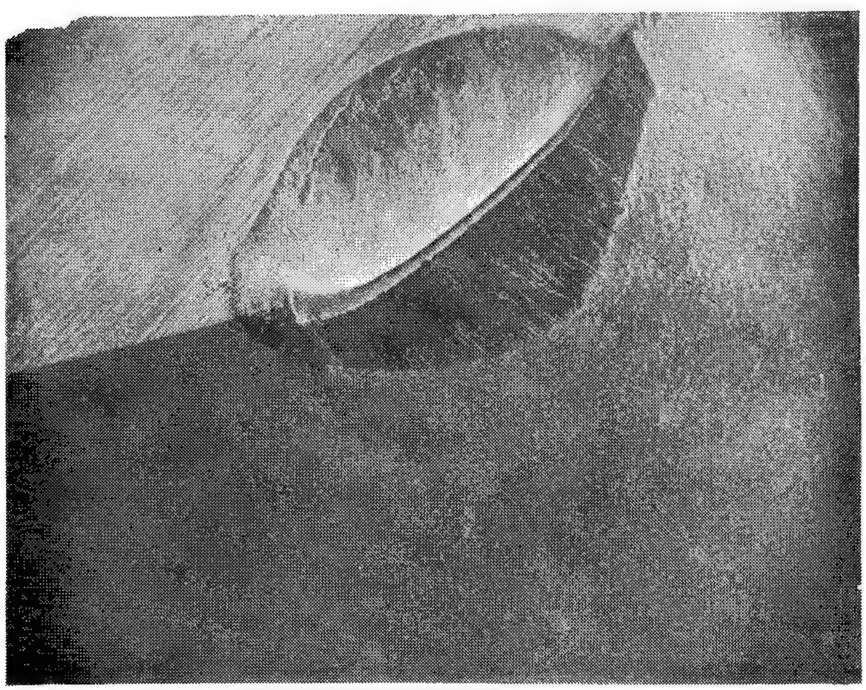
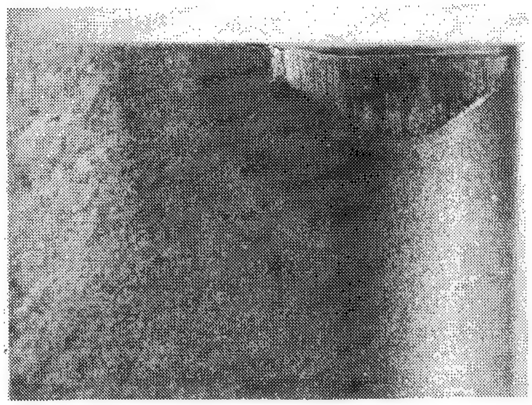


SEM (30X)

Figure 3.3-24. Photograph of a Typical Turning Test Tool for Fluid #2.



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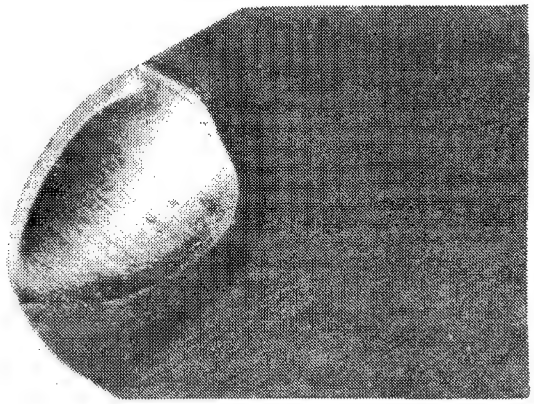

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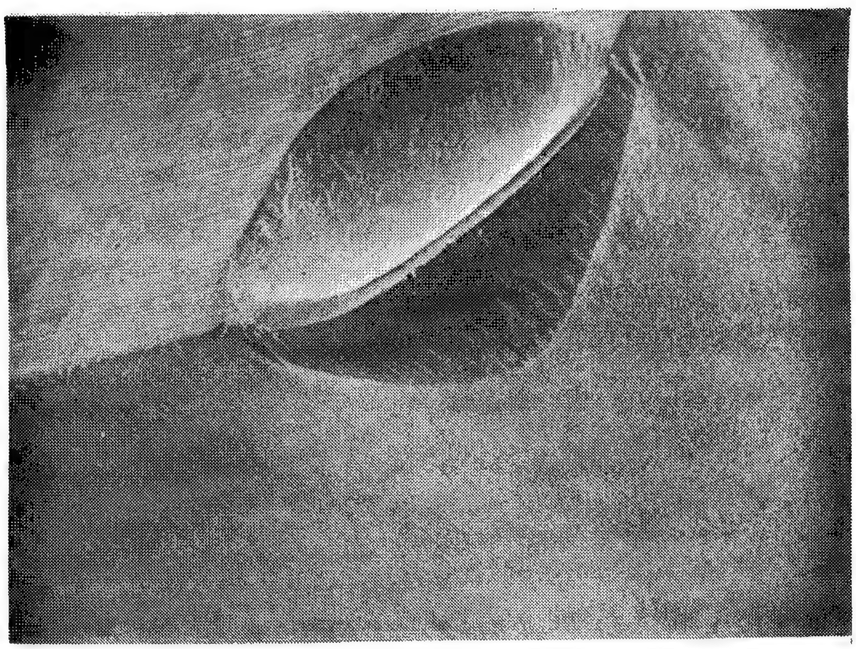
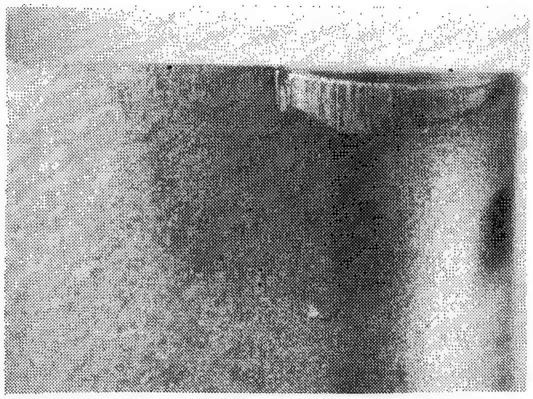
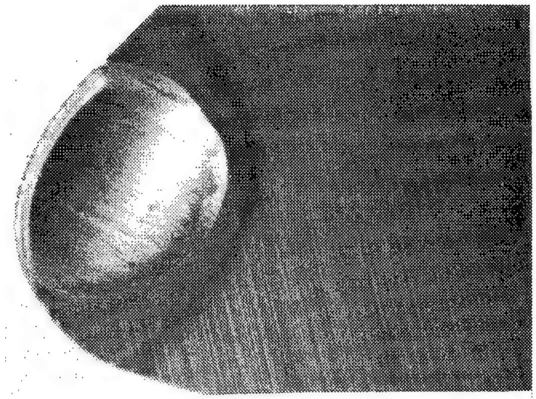
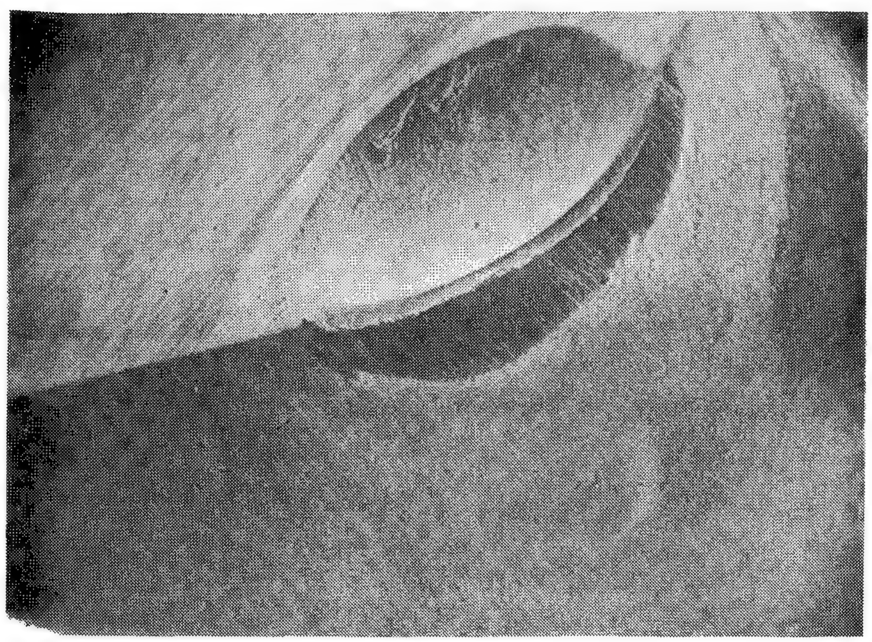


SEM (30X)

Figure 3.3-25. Photograph of a Typical Turning Test Tool for Fluid #3.

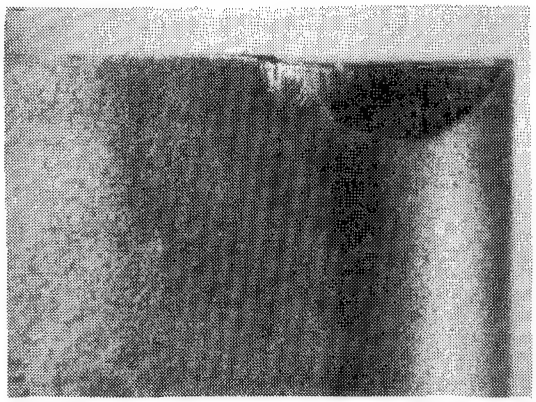
 

FLANK CRATER



SEM (30X)

Figure 3.3-26. Photograph of a Typical Turning Test Tool for Fluid #4.



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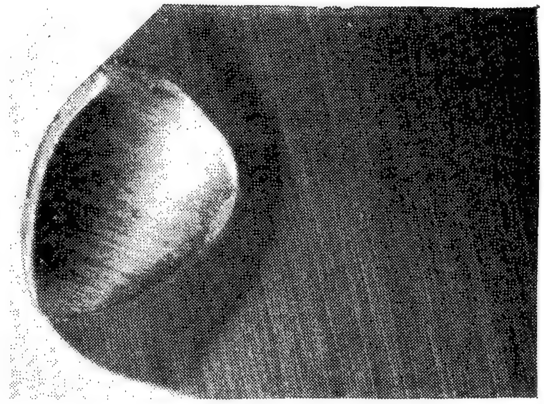

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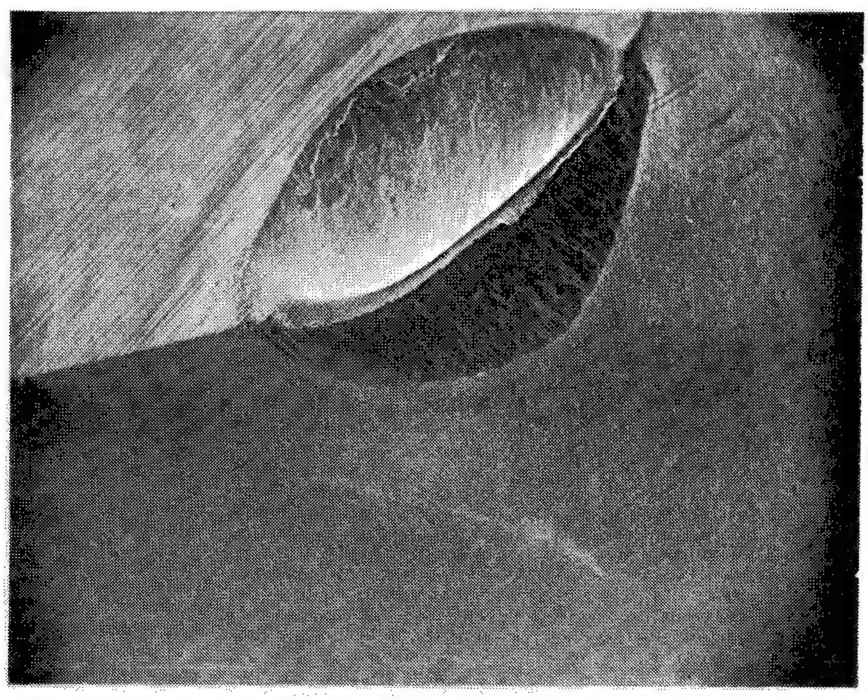
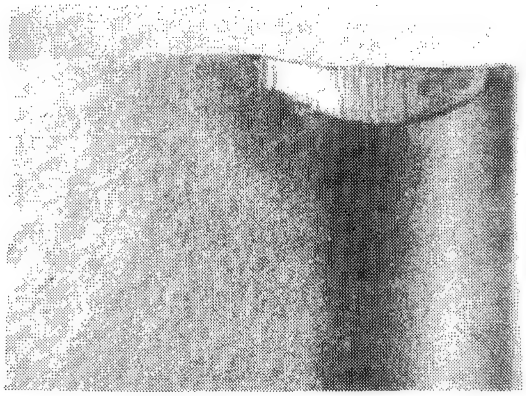


SEM (30X)

Figure 3.3-27. Photograph of a Typical Turning Test Tool for Fluid #7.



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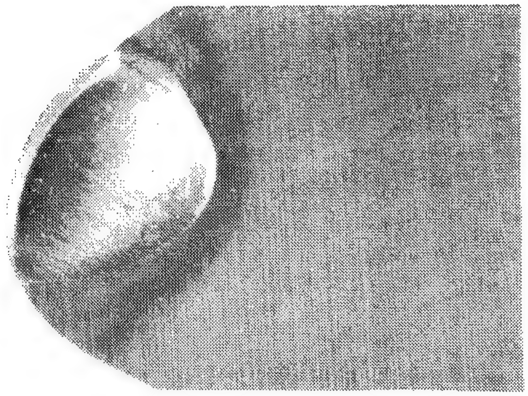

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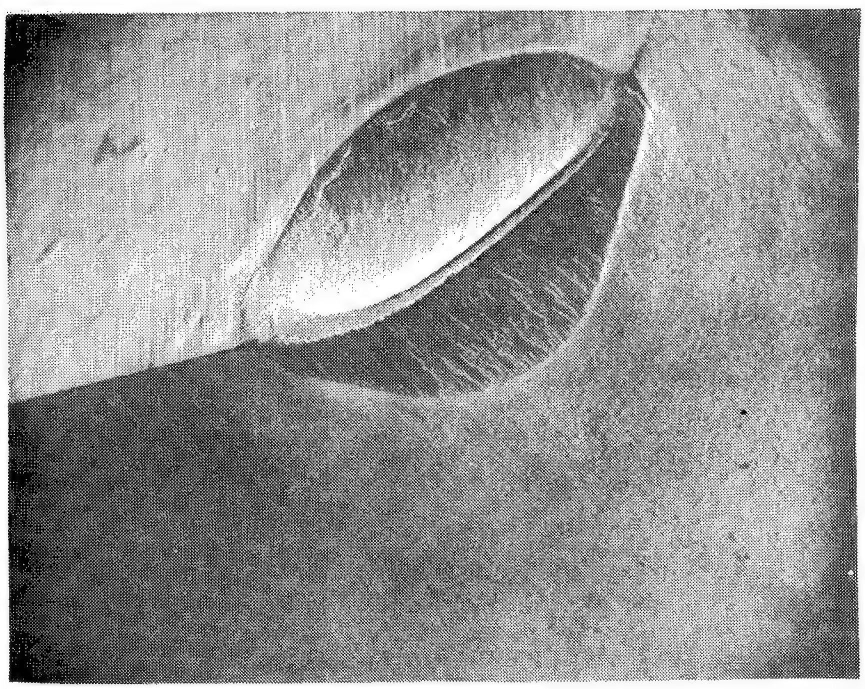
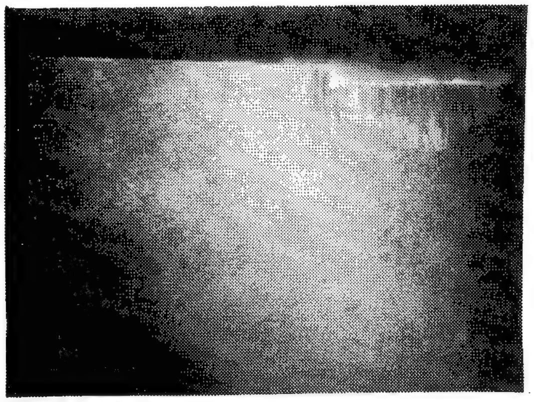
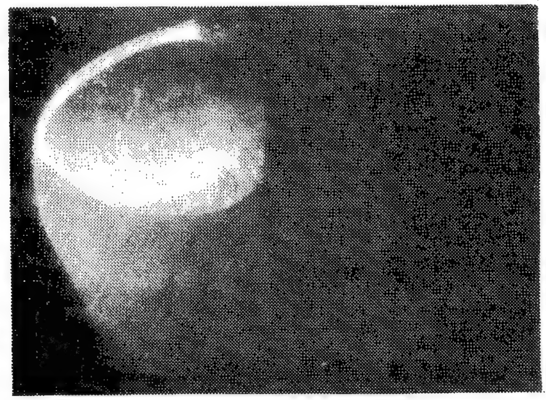


SEM (30X)

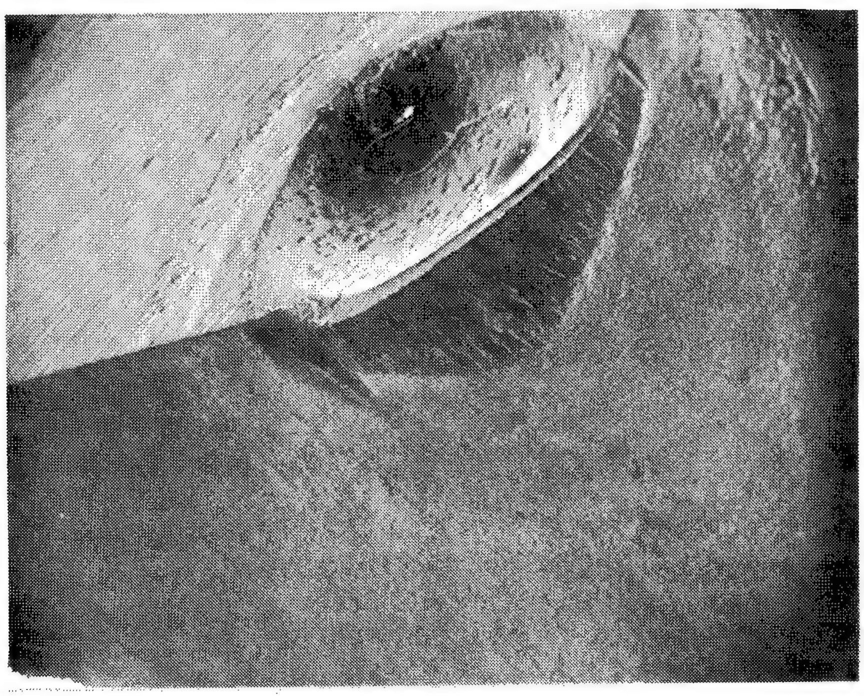
Figure 3.3-28. Photograph of a Typical Turning Test Tool for Fluid #8.



FLANK

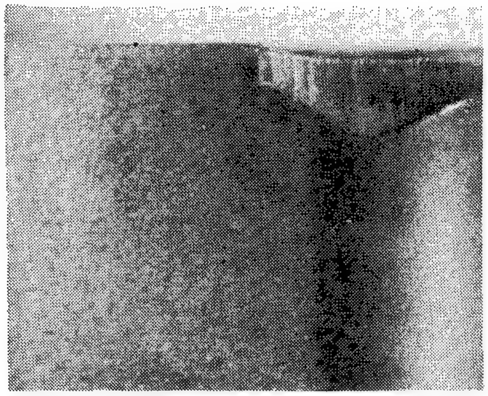


CRATER

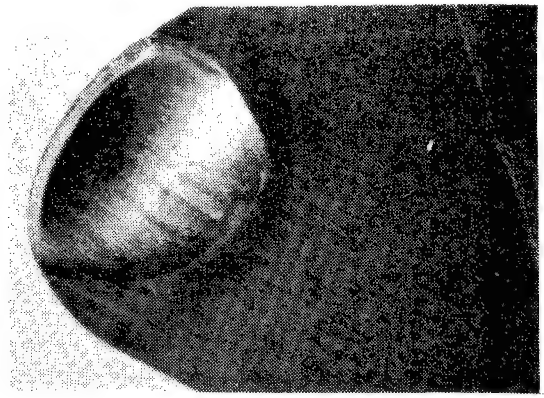


SEM (30X)

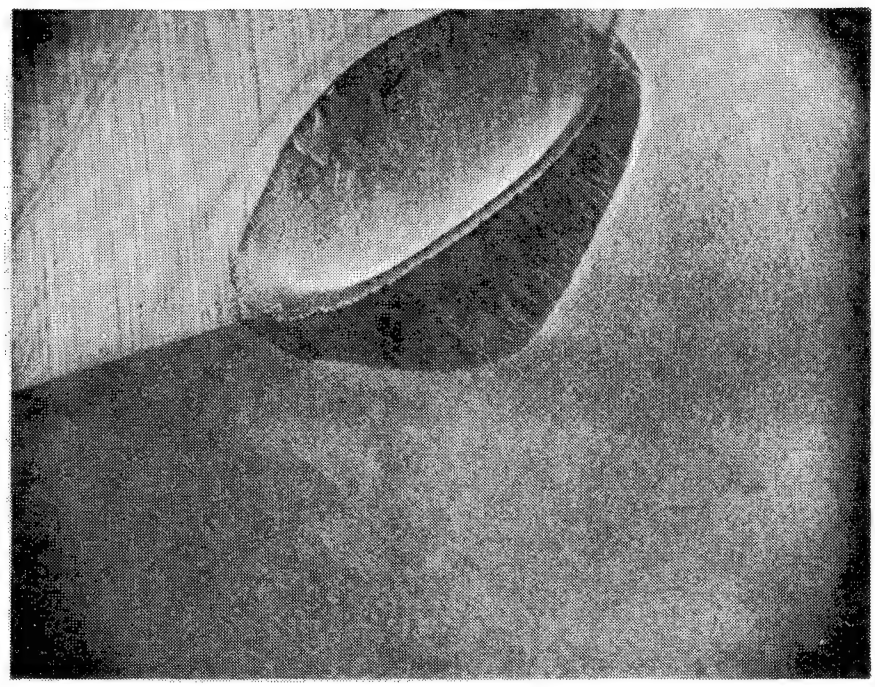
Figure 3.3-29. Photograph of a Typical Turning Test Tool for Fluid #15.



FLANK

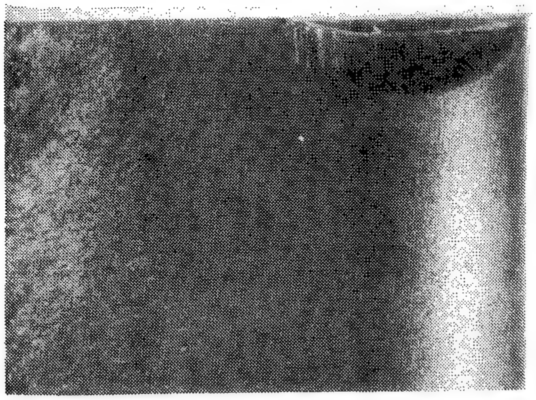


CRATER

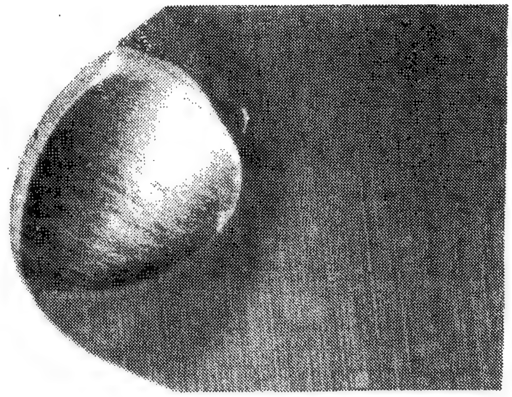


SEM (30X)

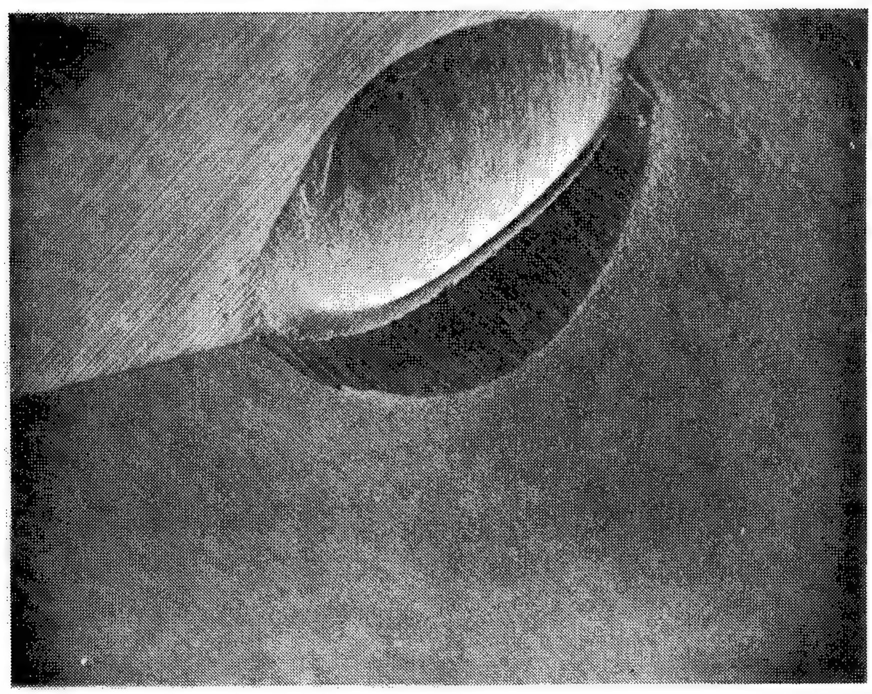
Figure 3.3-30. Photograph of a Typical Turning Test Tool for Fluid #32.



FLANK



CRATER

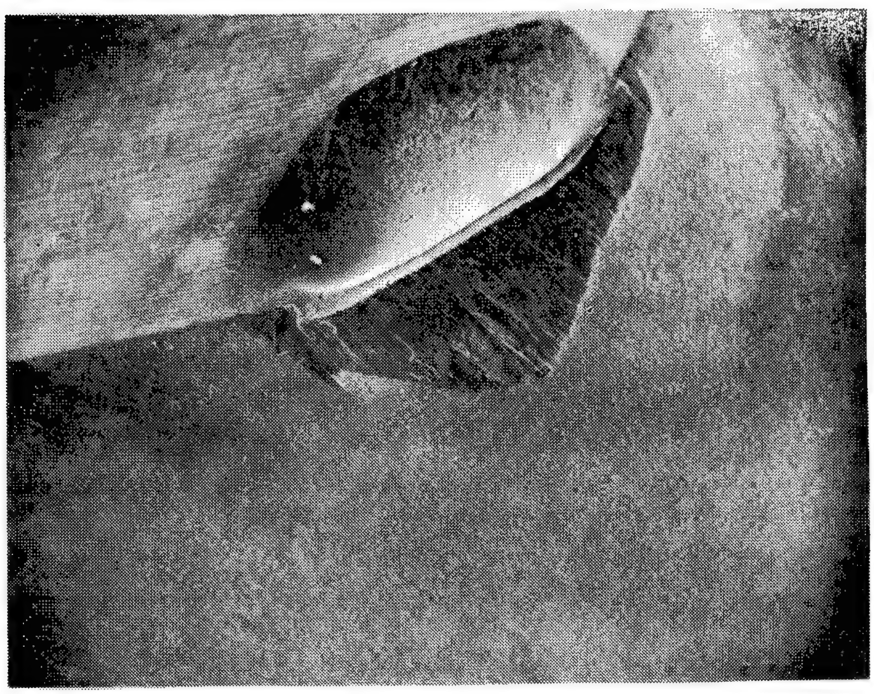


SEM (30X)

Figure 3.3-31. Photograph of a Typical Turning Test Tool for Fluid #33.

FLANK

CRATER



SEM (30X)

Figure 3.3-32. Photograph of a Typical Turning Test Tool for Fluid #34.

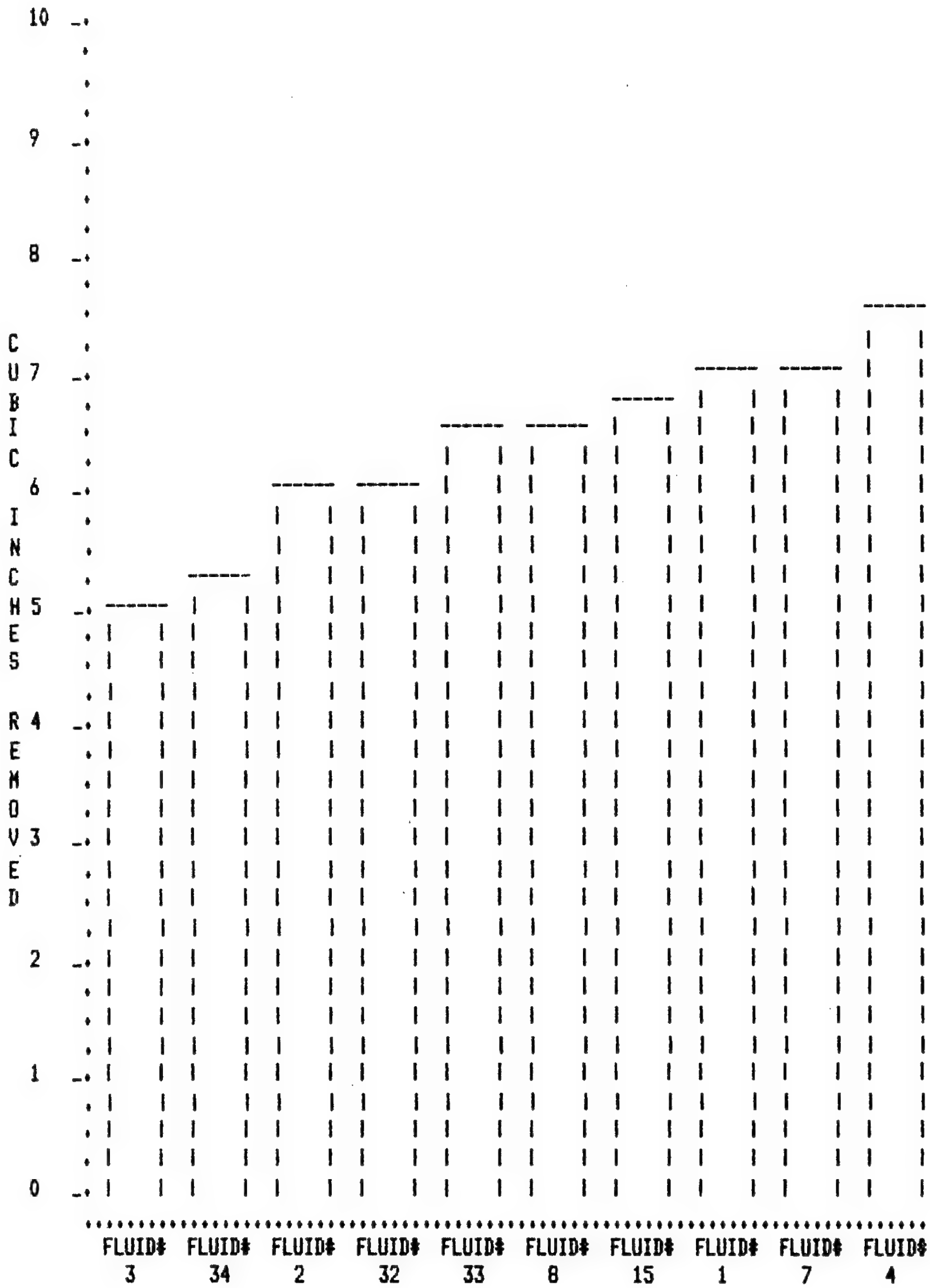


Figure 3.3-33. Cubic Inches of Metal Removed to .030" Flank Wear vs. Turning Fluids Tested.

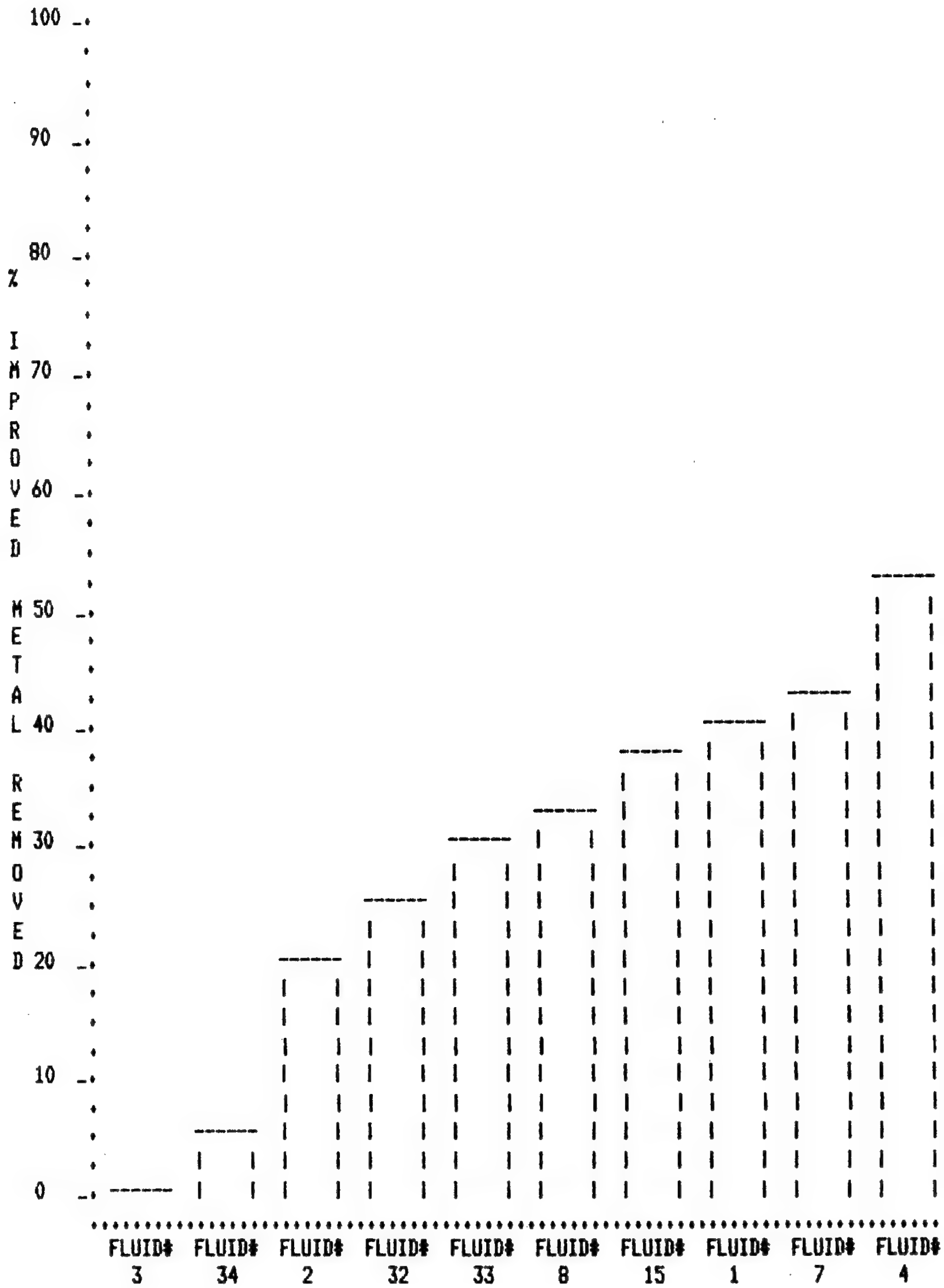


Figure 3.3-34. Percent of Increased Tool Life Compared to Test Fluid #3.

base for its low lubrication properties and moderate cooling ability. The poor performance of fluid #34, an emulsion with combined sulfur and chlorine, would seem to indicate that combining sulfur with chlorine at these test parameters does not produce optimal results. Fluid #32 is a full synthetic with chlorine added. The effective cooling properties of the synthetic fluid seem to reduce the effectiveness of the chlorine E.P. additive. This may be explained by the fact that chlorine needs a certain operating temperature to react. The cooling ability of the fluid may not allow the full benefits of the chlorine.

The 50 gallon sump cost of each of the test fluids are presented in Figure 3.3-35. Economically, fluid #7 offers the highest performance for the lowest price. Its $9.88 fifty gallon sump cost is 38% lower than any of the other high performing cutting fluids.

Additional tests were performed at 450 SFM and .026 inches per revolution feed on martensitic 4140 material hardened to R_c30. These tests were stopped at .010 of an inch of flank wear because the test results correlated to what was expected for these parameters. This was done in order to save time and material. These tests were only conducted to insure that other possible machining parameters were evaluated. The results of these tests are presented in Table 3.3-6. All of the fluids tested performed within about 15% of one another. This indicates that the severity of these parameters does not require a high performance cutting fluid. Any fluid selected for 800 SFM machining parameters will be effective for the 450 SFM parameters.

3.3.3 Cutting Fluid Application Matrix

After completing the many cutting fluid performance tests required for this program, it was concluded that, in order to develop a meaningful cutting fluid application matrix, many factors must be taken into account. The Phase I testing was devoted to testing with 4140 material in the hardness range of BHN 250. Phase II utilized a 90% martensitic structured 4140 material though hardened to R_c30. The Phase II machining was much more severe due to the increase in hardness and having the martensitic material structure. Reviewing the Phase I manufacturing survey shows that RIA uses both hardness ranges of 4100 series materials. Also, in grinding some stellite material is used. RIA's cutting fluid application matrix must take into account these different machining severities.

In order to fully understand the final cutting fluid application matrix, a presentation of how the matrix was formed will follow. This presentation will be divided into two parts. The first part will review the Phase I preliminary cutting fluid application matrix and incorporate the Phase II test data into this basic format. Then the concept of machining severity will be added which completes the data requirement for the final matrix. After the cutting fluid application matrix is presented, further explanation will be offered as to why specific generic types of fluids were selected for a particular application.

3.3.3.1 Review of the Phase I Preliminary Cutting Fluid Application Matrix and Addition of Phase II Data

In order to develop the preliminary cutting fluid application matrix, results of the cutting fluid tests were ranked for each machining process. This ranking was

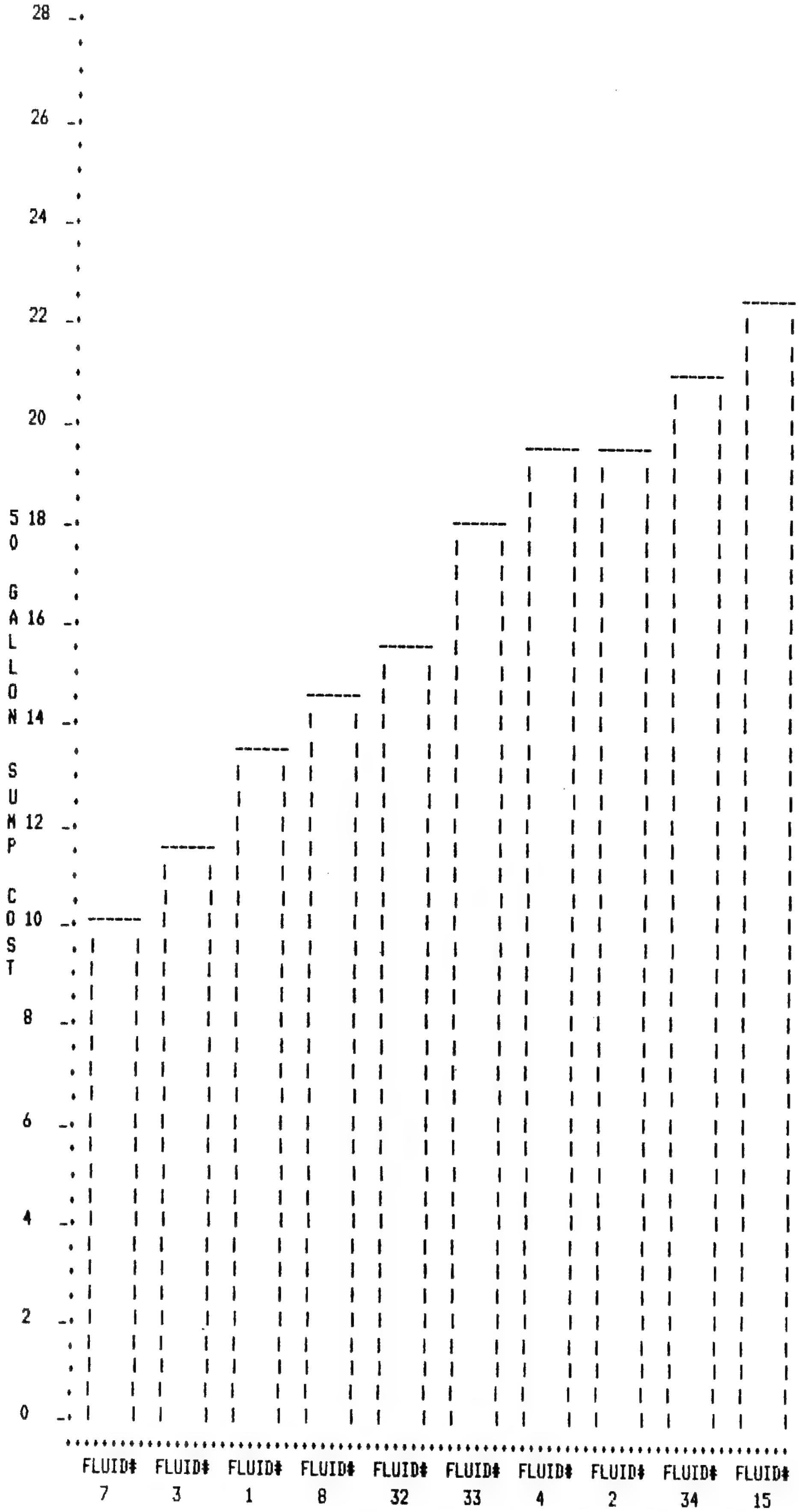


Figure 3.3-35. Price to Fill a 50 Gallon Sump vs. Turning Fluids Tested.

TABLE 3.3-6 TURNING TEST RESULTS FOR 450 SFM

Fluid #	TMR	Slope	Intercept	Average Cut Force	Average Radial Force	Average Feed Force	Avg. Power
1	11.1	.000766	.00520	177	74	74	8.6
2	9.8	.000973	.00421	188	76	77	8.8
3	10.9	.000857	.00533	185	78	74	8.6
4	12	.000828	.00434	181	74	74	8.5
7	10.5	.000858	.00514	183	77	76	8.7
8	11.2	.000784	.00522	186	77	78	8.8

accomplished by comparing each fluid to the worst performing fluid in the machining category being evaluated. The fluids having the highest percentage performance increase were ranked in group number three, and those with the lowest were positioned in group one. The remaining fluids were ranked in the middle or group two. For example, in the turning tests, Van Straaten's 550-P was the lowest performing fluid with the cubic inches to 0.030 inch flank wear (C.30 FW) equal to 10.20 cubic inches. Trimsol has a C.30FW of 20.41 cubic inches, which is a 100% improvement. Thus, Trimsol was positioned in group three. Norton 811 has a C.30FW of 16.59 cubic inches, which is a 63% improvement over 550-P and it is positioned in group two. When the cutting fluid test results are clustered close together, such as in grinding, the grouping is done slightly different. The highest performing fluids are positioned in group three. However, the lower performers are then placed in group two because they are so close to the high performers. No fluids are positioned in group one. All of the test fluid groupings are displayed in the following tables: Table 3.3-7, Turning; Table 3.3-8, Milling; Table 3.3-9, Drilling; and Table 3.3-10, Grinding. All the results were then grouped into one summary, Table 3.3-11.

The Phase II data were grouped using the same methodology. All of the Phase II test groupings are presented in the following tables: Table 3.3-12, Milling; Table 3.3-13, Turning; and Table 3.3-14, Summary.

3.3.3.2 Development of the Final Form of the Cutting Fluid Application Matrix

After examining Table 3.3-11 and Table 3.3-14, some differences were noted. Under the turning processes, some of the fluids that are in group 2 in the Phase I preliminary application matrix are in group 3 of the Phase II preliminary application matrix. Also, some fluids that are in the Phase II application, group 3, are in Phase I's application matrix, group 2. For example, Cimfree 238 is in group 2 in Phase I's preliminary cutting fluid application matrix and in group 3 in Phase II's preliminary cutting fluid application matrix. This indicates that different cutting fluid properties are needed in Phase II and Phase I testing series. The major differences between Phase I tests and Phase II tests are material hardness and material structure. Phase I tests were conducted with material in the range of BHN 250, while Phase II tests used material hardened to R_c30. Also, Phase II material contains a 90% tempered martensitic structure and the Phase I material contained tempered bainite. This data implies that the difference between the two RIA cutting fluid program phases is machining process severity. Phase II was conducted at a greater severity level than the Phase I tests. The higher the machining severity is, the more the process needs cooling and/or high temperature E.P. lubricants. Cimfree 238 is a fluid that has good cooling properties and minor lubricating properties. This is why it performed better in the Phase II tests than the Phase I tests. Phase II's harder material required more cooling than Phase I's softer material.

The same is true for milling. Phase I's milling process was less lubrication and thermal shock sensitive than Phase II's. This is due to the fact that less heat was generated while machining the softer material. For example, Cimfree 238 was positioned in group 3 in the Phase I preliminary cutting fluid matrix. In the Phase II preliminary cutting fluid application matrix, it was positioned in group 1. Cimfree 238 has a high cooling and moderate lubrication properties. The high cooling properties produced a thermal shock effect in the Phase II testing. During the Phase I testing, the machining was not severe enough to create a thermal shock problem.

TABLE 3.3-7

TURNING CUTTING FLUIDS GROUPED BY TEST PERFORMANCE

Group	Fluid	Manufacturer	Type	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1	550-P	Van Straaten	SS	C			$11.48
	470	DoAll	E				$18.40
	MX-5080	Economics Labs	FS			+	$26.27
2	Adcool-3	Valvoline	FS	C	S	+	$17.69
	Wheelmate 811	Norton	E	C			$21.00
	Wheelmate 674	Norton	SS		S		$16.50
	Cimfree 238	Cin. Milacron	FS			++	$13.61
3	Trimsol	Master Chemical	E	C			$19.62

Key:

1 = Low Performance
2 = Medium Performance
3 = High Performance

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic

C = Chlorine
S = Sulfur
+ = Other

TABLE 3.3-8

MILLING CUTTING FLUIDS GROUPED BY TEST PERFORMANCE

Group	Fluid	Manufacturer	Type	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1	Adcool-2	Valvoline	FS			+	$10.65
	Trimsol	Master Chemical	E	C			$19.62
2	550-P	Van Straaten	SS	C			$11.48
	Wheelmate 674	Norton	SS		S		$16.50
3	Cimfree 238	Cin. Milacron	FS			++	$19.62
	470	DoAll	E				$18.40

Key: 1 = Low Performance
2 = Medium Performance
3 = High Performance

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic

C = Chlorine
S = Sulfur
+ = Other

TABLE 3.3-9

DRILLING CUTTING FLUIDS GROUPED BY TEST PERFORMANCE

Group	Fluid	Manufacturer	Type	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1	Trimsol	Master Chemical	E	C			\$19.62
	470	DoAll	E				\$18.40
	Adcool-2	Valvoline	FS			+	\$10.65
2	Wheel Mate 674	Norton	SS		S		\$16.50
3	Cimfree 238	Cin. Milacron	FS			+++	\$13.61

Key: 1 = Low Performance
2 = Medium Performance
3 = High Performance

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic

C = Chlorine
S = Sulfur
+ = Other

TABLE 3.3-10

GRINDING CUTTING FLUIDS GROUPED BY TEST PERFORMANCE

Group	Fluid	Manufacturer	Type	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1							
2	5 Star 40	Cin. Milacron	SS				$11.01
	Adcool-2	Valvoline	FS			+	$10.65
3	Trimsol	Master Chemical	E	C			$19.62
	Cimfree 238	Cin. Milacron	FS			++	$13.61

Key:

1 = Low Performance
2 = Medium Performance
3 = High Performance

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic

C = Chlorine
S = Sulfur
+ = Other

TABLE 3.3-11

PHASE I. PRELIMINARY CUTTING FLUID APPLICATION MATRIX

Manufacturing Process	Group 1	Group 2	Group 3
Milling	Adcool-2, Valvoline Trimsol, Master Chemical	Wheelmate 674, Norton 550-P, Van Straaten	Cimfree 238, Cin. Milacron 470, DoAll
Turning & Boring	550-P, Van Straaten 470, DoAll MX-5080, Economics Labs	Adcool-3, Van Straaten Wheelmate 811, Norton Wheelmate 674, Norton Cimfree 238, Cin. Milacron	Trimsol, Master Chemical
Drilling	Trimsol, Master Chemical 470, DoAll Adcool-2, Valvoline	674, Norton	Cimfree 238, Cin. Milacron
Grinding		Cimcool 5 Star 40 Adcool-2, Valvoline	Cimfree 238, Cin. Milacron Trimsol, Master Chemical

Key: Group 1 = Low Performance
Group 2 = Medium Performance
Group 3 = High Performance

TABLE 3.3-12

MILLING CUTTING FLUIDS GROUPED BY TEST PERFORMANCE

Group	Fluid	Manufacturer	Type	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1	#1, Cimfree 238	Cin. Milacron	FS			++	$13.61
	#31, SYN PYNK 880	Pillsbury	SS				$ 7.25
	#4, Cimcool 400	Cin. Milacron	FS			+++	$19.28
	#2, Trimsol	Master Chemical	E	+			$19.62
2	#D, Dry	-	-				-
3	#0, VACMUL	Mobil Oil	O	+	+		$157.50
	#8, DASCOOL 502	Stuart Oil	SS			++	$14.42

Key:
1 = Low Performance
2 = Medium Performance
3 = High Performance

C = Chlorine
S = Sulfur
+ = Other

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic

TABLE 3.3-13

TURNING CUTTING FLUIDS GROUPED BY TEST PERFORMANCE

Group	Fluid	Manufacturer	Type	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1	#3, 550P	Van Straaten	SS				$11.48
	#34, 811	Norton	E	C	S		$21.00
2	#2, Trimsol	Master Chemical	E	C			$19.62
	#32, Trim HD	Master Chemical	FS	C			$15.71
	#33, Trim LC	Master Chemical	E			+	$17.88
	#8, DASCOOL 502	Stuart Oil	SS			++	$14.42
3	#15, Lubricoolant 925	DuBois	FS			++	$22.35
	#1 CIMFREE 238	Cin. Milacron	FS			++	$13.61
	#7, Gulf Cut HD	Gulf Oil	E		S		$ 9.88
	#4, Cimcool 400	Cin. Milacron	FS			+++	$19.28

Key:
1 = Low Performance   C = Chlorine
2 = Medium Performance   S = Sulfur
3 = High Performance   + = Other

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic

TABLE 3.3-14

PHASE II. PRELIMINARY CUTTING FLUID APPLICATION MATRIX

Manufacturing Process	Group 1	Group 2	Group 3
Milling	#2, Cimfree 238, Cin. Milacron #31, SYN PYNK 880, Pillsbury #4, Cimcool 400, Cin. Milacron #2, Trimsol, Master Chemical	#D, No Fluid	#0, VACMUL Oil, Mobil Oil. #8, DASCOOL 502, Stuart Oil
Turning & Boring	#3, 550P, Van Straaten #34, 811, Norton	#2, Trimsol, Master Chemical #32, Trim HD, " #33, Trim LC, " #8, DASCOOL 502, Stuart Oil	#15, Lubricoolant 925 DuBois #2, Cimfree 238, Cin. Milacron #7, Gulfcut HD, Gulf Oil

Key: Group 1 = Low Performance
Group 2 = Medium Performance
Group 3 = High Performance

The Cutting Fluid Application Matrix is based on RIA process severity and the principles described above. THE FLUIDS THAT ARE DISPLAYED IN THE MATRIX ARE FOR EXAMPLE PURPOSES ONLY AND ARE NOT MEANT TO BE AN ENDORSEMENT BY TRW OF A PARTICULAR CUTTING FLUID. Table 3.3-15 displays the Cutting Fluid Application Matrix.

3.3.3.3 Explanation of the Cutting Fluid Application Matrix

The Cutting Fluid Application Matrix which is displayed in Table 3.3-15 is designed to relate GENERIC cutting fluid qualities that are based on laboratory performance tests to SPECIFIC RIA MACHINING PARAMETERS. Initially, in this report, Table 3.2-1 was presented as an example to show how some cutting fluid companies describe their products. Both the Phase I and Phase II program testing has shown that these descriptions (heavy duty, light duty, etc.) of cutting fluids can be misleading. The test results demonstrate that some fluids perform well for certain machining operations while others perform superior on others.

The main criteria for cutting fluid selection must be machining severity and generic cutting fluid requirements of a particular manufacturing operation. The severity of all the machining operations has been characterized and presented in sections 3.1.4 through 3.1.8 in this report. The RIA Cutting Fluid Application Matrix utilizes the overall severity designations described in this report and relates them to the Phase I and Phase II test results. For example, the milling operations for an overall severity rank of 3 at RIA are lubrication sensitive and require a cutting fluid with a high degree of lubricating properties. Also, it is important that these lubricating properties get to where they are needed. Therefore, an effective wetting action is required for a milling operation. How the Cutting Fluid Application Matrix works can best be described by this example. Table 3.3-15 under milling severity rank 3 exhibits the following information which is typed in capital letters followed by a short explanation of what the information means.

HARDNESS/MATL - R_c30/4100

The hardness/material is a restatement of what can be found in the severity section in this report under an overall severity index of 3 for milling. It is reproduced on the table for ease of future use. An overall milling severity rank 3 is for milling of 4100 series material at 600-700 SFM at 0.002-0.003 chip load.

MINIMUM FLUID REQUIREMENTS - HL, SC, EW

This describes the minimum GENERIC cutting fluid requirements for milling with an overall severity rank of 3. The abbreviations stand for qualities a milling fluid must have to perform well under this severity level as demonstrated in the Phase I and Phase II testing. The abbreviations as found in Table 3.3-15's key stand for: HL, High Lubricity; SC, Slight Cooling; and EW, Effective Wetting.

EXAMPLE FLUID - DASCOOL 502, STUART OIL

This is an EXAMPLE of the GENERIC type of fluid described in the MINIMUM FLUID REQUIREMENTS.

TABLE 3.3-15
RIA CUTTING FLUID APPLICATION MATRIX BASED ON TRW'S LABORATORY PERFORMANCE TESTS

MANUFACTURING PROCESS		SEVERITY RANK 1	SEVERITY RANK 2	SEVERITY RANK 3	SEVERITY RANK 4	SEVERITY RANK 5
BROACHING	Hardness/Mat'l					Stellite
	Minimum Fluid Requirements	NPA	NPA	NPA	NPA	HL, SC, SW
	Alternate Fluid Requirement					
	Example Fluid					Topaz 7/150 Oil Poly-Form Oils
DRILLING	Hardness/Mat'l		R_c 30/4100		R_c 30/4100	
	Minimum Fluid Requirements	NPA	HL, SC, EW	NPA	HL, SC, SW	NPA
	Alternate Fluid Requirements					
	Example Fluid		DASCOOL 502 Stuart Oil*		VACMUL (S,CL) Mobil Oil*	
GRINDING	Hardness/Mat'l		R_c 30/4100			Stellite
	Minimum Fluid Requirements	NPA	SL, MC, SW	NPA	NPA	HL, SC, SW
	Alternate Fluid Requirements					
	Example Fluid		Cimfree 238 Cin. Milacron*			VACMUL (S,CL) Mobil Oil*
MILLING	Hardness/Mat'l	250BHN/4100	R_c 30/4100	R_c 30/4100		
	Minimum Fluid Requirements	ML, SC, SW	HL, SC, EW	HL, SC, EW	NPA	NPA
	Alternate Minimum Fluid Requirements					
	Example Fluid	470, DoAll*	DASCOOL 502 Stuart Oil*	DASCOOL 502 Stuart Oil*		
TURNING & BORING	Hardness/Mat'l	250BHN/4100	R_c 30/4100	R_c 30/4100		
	Minimum Fluid Requirements	ML, SC, SW	ML, EC, SW	ML, EC, SW	NPA	NPA
	Alternate Fluid Requirements		HL, MC, SW	HL, MC, SW		
	Example Fluid	Trimsol, Master Chemical*	Cimcool 400, Cin. Milacron*	Gulfcut HD Gulf Oil*		

*THE FLUIDS PRESENTED AS EXAMPLES ARE NOT AN ENDORSEMENT OF A PARTICULAR CUTTING FLUID BY TRW BUT AN EXAMPLE OF A PARTICULAR **GENERIC** TYPE.

Lubrication -
HL: High Lubricity
ML: Medium Lubricity
SL: Moderate Lubricity

Cooling -
EC: Extreme Cooling
MC: Moderate Cooling
SC: Slight Cooling

Wetting Action -
EW: Effective Wetting
SW: Slight Wetting
NW: No Wetting

NPA - No process applicable

The Phase III program effort will add to the data contained in Table 3.3-15 to include necessary economic considerations. These considerations will include fluid sump life and waste disposal costs.

3.3.4 Material Microstructure Effects on Machinability

Great precautions were taken while conducting the RIA machining simulation testing to insure that workpiece material and cutting tool insert variations were kept to a minimum. This was done in order to insure accurate test results. From past test experience, it was known that variations in workpiece material had the highest probability of occurrence. Therefore, various precautions were taken when ordering the material and double checks were built into the test design to detect any occurrences of material variation.

The following will describe the effects encountered by a material variation during the Phase II testing. Initially, the test design was based on the criteria that all of the material used would be of a consistent nature. 4140 material was ordered in the form of a 6 inch diameter x 120 inch long cylinder having a 2 inch hole through the center. The bar was purchased with a through-hole to allow for a more uniform heat treatment. Then the bar was heat treated to R_c 29-32 and cut into ten test specimens. A section was cut (not from the ends) and examined for hardness, decarburization depth and metallurgical structure. This initial test indicated that the average Tukon hardness converted to Rockwell "C" was 30.5 from the regions beyond the outside diameter decarb to 1 inch from the inside wall diameter. This was the region at which all tests would be performed. Also, small amounts of blocky ferrite were observed.

Testing was initiated at the 5.5 inch diameter in order to be sure that machining would be done in an area of uniform hardness. The first tests were performed using the cutting fluids that would offer extreme results. A fluid was tried that should show superior results on test bar #7. The fluid did so well the test had to be continued on test bar #8. Then a fluid was tried that was supposed to do poorly on test bar #2. However, this fluid performed extremely poorly leaving quite a bit of test material on test bar #2. A verification test was run using the superior fluid on the remaining material of test bar #2. The verification test did not show the extreme difference in total metal removed as the test conducted on test bars #7 and #8. Deductively, bar #2 is more difficult to machine than bars 37 and #8.

This extreme difference prompted further metallurgical examination. First, all of the test bars had sections cut from their chucked (full diameter) ends. These sections were then checked for Rockwell (c) hardness (see Figure 3.3-36). As can be seen in Figure 3.3-37, some variations in hardness were observed; therefore, a complete metallurgical examination of test bars #2, 7 and 8 was conducted. The easier to machine bar, #7, has a microstructure of tempered martensite with 15% of its volume containing free (blocky) ferrite at the diameter of the cutting fluid testing (see top half of Figure 3.3-38). Bar #2, the difficult to machine bar, was found to contain a tempered martensite structure containing no free (blocky) ferrite at the diameter of cutting fluid testing (see bottom half of Figure 3.3-38). Ten percent of the volume of bar #8 was found to be blocky ferrite. Blocky ferrite is known to be easier to machine than tempered martensite because it is softer and not as tough. A harder material

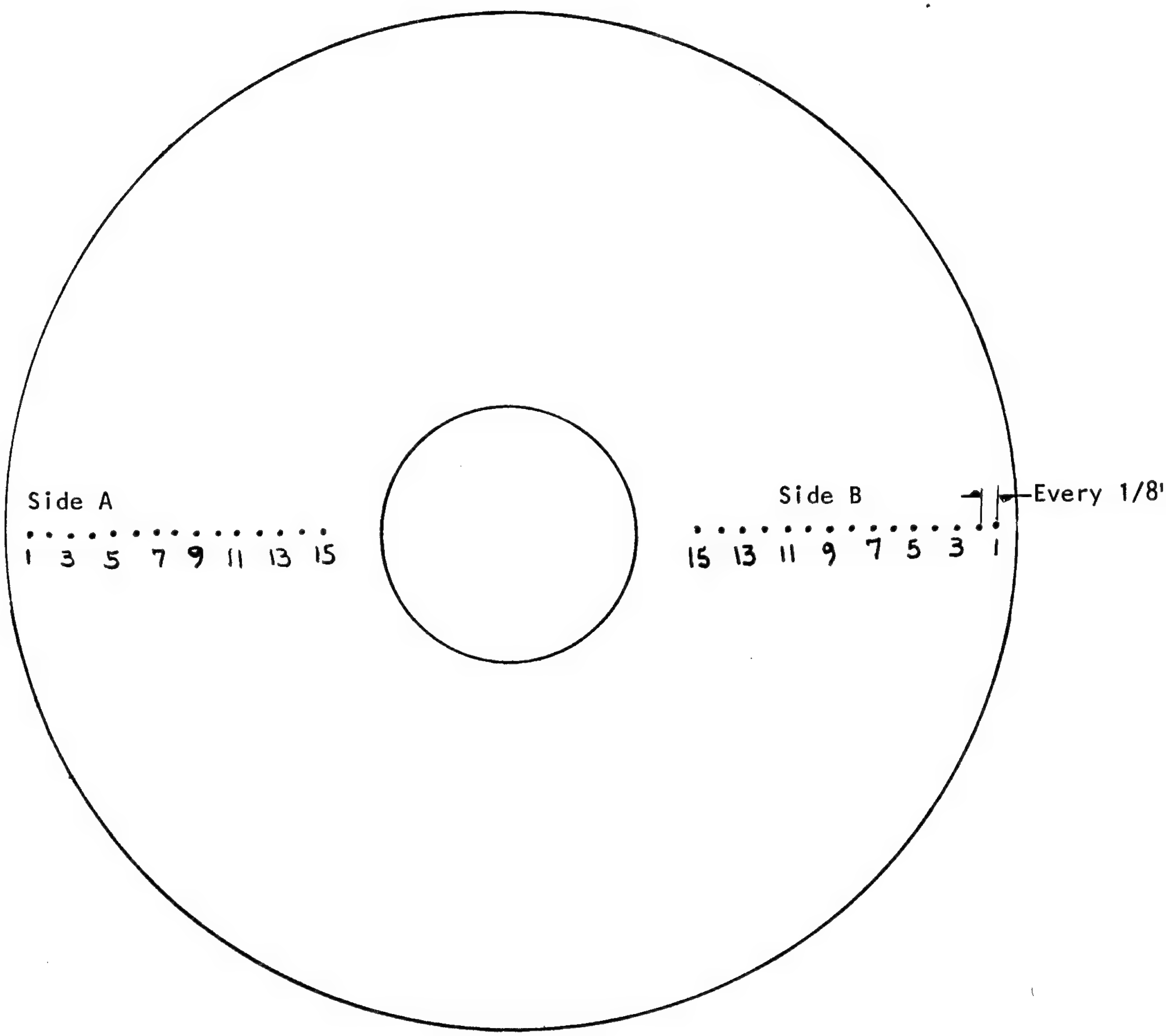


Figure 3.3-36. Procedure for Rockwell Hardness Test.

BAR #	'A' $\bar{X}$ $\pm$ s	'B' $\bar{X}$ $\pm$ s	Range ('A' & 'B'
1	33.2 $\pm$ .52	33.0 $\pm$ .95	31.7 - 34.7
2	30.80 $\pm$ .55	30.14 $\pm$ .83	28.4 - 31.8
3	29.84 $\pm$ .63	29.72 $\pm$ .71	28.7 - 30.9
4	28.45 $\pm$ .25	29.90 $\pm$ .73	28.1 - 31.7
5	30.25 $\pm$ .84	30.28 $\pm$ .66	28.5 - 31.4
6	29.16 $\pm$ 1.12	29.50 $\pm$ .51	27.9 - 31.8
7	28.83 $\pm$ .66	28.93 $\pm$ .25	27.8 - 29.9
8	28.88 $\pm$ .67	28.82 $\pm$ .52	27.8 - 29.8
9	29.24 $\pm$ .40	28.68 $\pm$ .53	28.0 - 29.7
10	28.38 $\pm$ 1.03	28.32 $\pm$ .63	26.5 - 29.8

Note: Points 1-3 and 14-15 were not used in the calculations because the material they occupy would not be used for testing.

Key: 'A' = 'A' hardness traverse (see Figure 1)

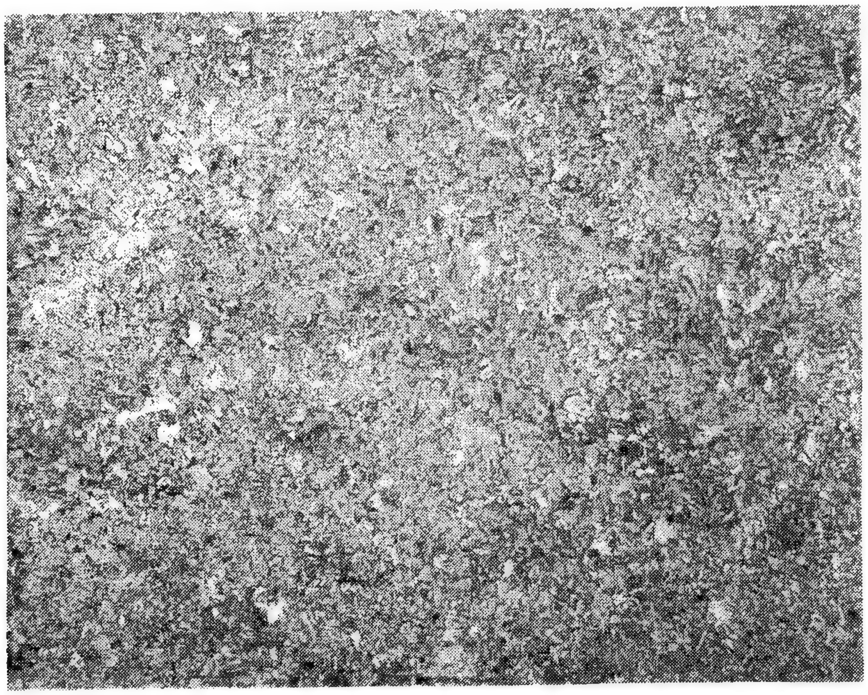
'B' = 'B' " " "

$\bar{X}$ = mean of points 4 - 14

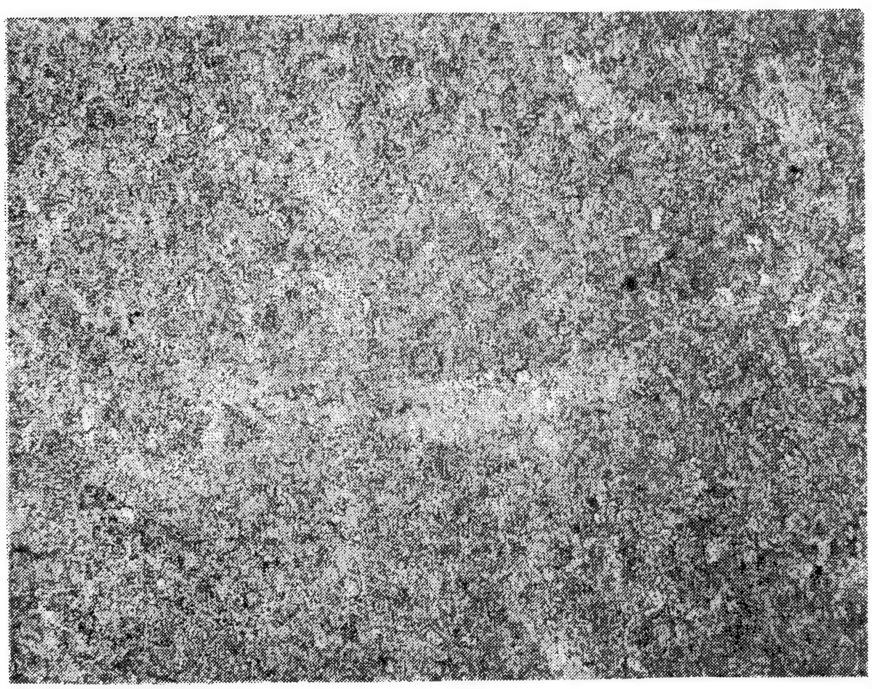
S = standard deviation of points 4 - 14

Range = (Lowest point of 'A' & 'B') - Highest point of 'A' & 'B'

FIGURE 3.3-37. RIA PHASE II TURNING HOLLOW BAR HARDNESS ANALYSIS



Bar #7 Blocky Ferrite



Bar #2 Martensite

Figure 3.3-38. Photomicrograph (100X) of the Easier to Machine Bar #7 to the More Difficult to Machine Bar #2.

creates more friction and causes more wear than a softer material. Toughness can be related to a cutting tool creating a crack in the workpiece material — the tougher the material, the more difficult to form the crack.

Further comparison tests were performed on bar #2 and bar #7. Using the same cutting fluid and machining parameters, a 50% increase in total metal removed was observed between bar #2 and bar #7. All tests were conducted using the RIA machining parameters.

These test results demonstrate the relationship between machinability and material microstructure. This further amplifies the need for exact material specifications for a particular product. To date, very little research has been generated in this area. The potential for increased productivity through the selection of a more machinable material within a wide material specification is yet to be achieved. Machining Technology recommends that the Rock Island Arsenal further explore this area.

4.0 CONCLUSIONS

As a result of Phase I and Phase II's activities, a series of conclusions and observations have been developed which can be conveniently subdivided into the following categories: RIA manufacturing processes and materials, RIA current cutting fluid system, and fluid testing conclusions.

These categories as they apply to the overall manufacturing operation being conducted at the Rock Island Arsenal will be treated individually in the following subsections.

4.1 RIA Manufacturing Processes and Materials

A. Ninety-one percent of RIA manufacturing are comprised of four processes.

Ninety-one percent of all the manufacturing processes at the Arsenal are turning and boring, milling, drilling and grinding. This figure is based on monthly operating hours.

B. Ninety-five percent of all parts in the observed machining operations were manufactured with 4100 series steel.

During the visits to RIA, seventy-six machining operations were observed on twenty-four different parts. Over 95% of these operations were manufactured with 4100 series steel. Some bronze machining was observed being done for wear surfaces. This operation seemed to require metallurgical process optimization rather than cutting fluid improvements. An extremely minor amount of aluminum and cast iron machining is performed at RIA.

C. Chipping and cratering were the observed tool wear modes.

Seventy-five percent of the observations for turning and boring exhibited either extreme wear due to chipping or extreme wear due to cratering without evidence of flank wear or BUE effects. All of the observed carbide insert wear for milling was in the form of chipping. The turning operations observed exhibited chipping and extreme crater wear.

D. The majority of machining operations were performed at state-of-the-art parameters.

Most of the N/C turning and milling operations were performed well beyond Machinability Data Handbook type machining parameters. These operations utilized the most advanced tooling available. Also, the foremen in the conventional machining areas were well informed about the latest tooling and machining parameters and used them where possible. Their only limitations are the older equipment they must utilize.

4.2 RIA Current Cutting Fluid System

A. RIA needs some form of cutting fluid recycling system.

Currently, it is estimated that RIA is using 7,558 gallons of water-base cutting fluid and 4,556 gallons of neat oil cutting fluid a year. Also, 15,000 gallons of spent cutting fluid must be disposed of each month. This volume of new cutting fluid input and the present rate of disposal indicates that installing some form of recycling system would be an appropriate course of action.

As of December 1981, RIA has purchased a centrifuge-type batch processing cutting fluid reclaiming system. This has been scheduled to become operational in FY82.

B. Anerobic bacteria is the main reason for cutting fluid sump changes.

One result of the manufacturing survey indicated that the main reason for changing a machine's sump was that it emitted a foul odor. Not one person interviewed ever heard of anyone seeing an emulsion split. This indicates that the anerobic bacteria are causing GOOD cutting fluid not to be fully utilized and these bacteria must be controlled.

C. Cutting fluid concentrations are not at the manufacturer's recommended levels.

The data obtained to date seem to indicate improvements in manufacturing operations at Rock Island Arsenal can be achieved through modification of the present cutting fluid selection and maintenance systems. For example, the concentration level of the Master Chemical product Trimsol and the Cincinnati Milacron product Cimfree 238 have been utilized below the manufacturer's suggested concentration levels in many of the observed machine sumps. This problem may be attributed to one or a combination of the following:

1. Selecting a make-up fluid concentration that is too lean for the type of fluid loss.

There are three main types of fluid loss: chip dragout, splashout and evaporation. Evaporation is a natural process that removes water from the sump leaving the fluid concentrate which causes the remaining fluid to carry a higher cutting fluid concentration level than the initial charge. Dragout and splashout remove water and concentrate together leaving the remaining fluid at its current concentration level. Each of these conditions requires a different concentration make-up fluid to bring the sump to the desired level.

2. Utilizing an inaccurate method to mix the make-up fluid.

The make-up fluid mixture may unknowningly be mixed too lean by the Venturi type mixing system currently in operation.

3. Contamination oils and/or bacteria may be diluting the sump concentration.

Tramp oils and bacteria have the ability to reduce the effectiveness of the cutting fluid which causes it to perform as if it lacks concentration (refer to Section 3.3.1 of the Phase I report for clarification).

4. Utilizing an inaccurate method of measuring cutting fluid concentration.

A refractometer may not always be an accurate method to determine fluid concentration. Contaminants may become emulsified into the oil which make it appear to contain a higher than actual concentration. Also, a refractometer may not be recommended with all cutting fluids. For example, the Cincinnati Milacron Company recommends titration as the most accurate method of concentration measurement for Cimfree 238. Section 5.0 will make recommendations which have the potential to alleviate these problems.

4.3 Fluid Testing Conclusions

A. All of the turning carbide tools tested failed due to flank wear.

As illustrated in Figure 4.3-1, insert chipping or excessive crater wear did not cause the test tools to fail. The only source of tool failure was flank wear. In general, a good balance between crater wear and flank wear was observed. This is contrary to the observed tool wear modes experience at RIA, which involved chipping and crater wear failures. The machining tests were all conducted at the manufacturer's recommended concentration levels. The majority of the machine sumps observed at RIA had much lower concentration levels. A logical deduction is: as the concentration of a cutting fluid decreases below its recommended level, tool wear will increase. This is based on the fact that, for the most part, the cutting fluid tests were conducted utilizing the same machining parameters and employing the same cutting fluids used at RIA.

B. Milling is a lubrication sensitive process.

The milling tests proved that the RIA machining parameters require the following properties in a cutting fluid:

1. A high degree of lubrication.

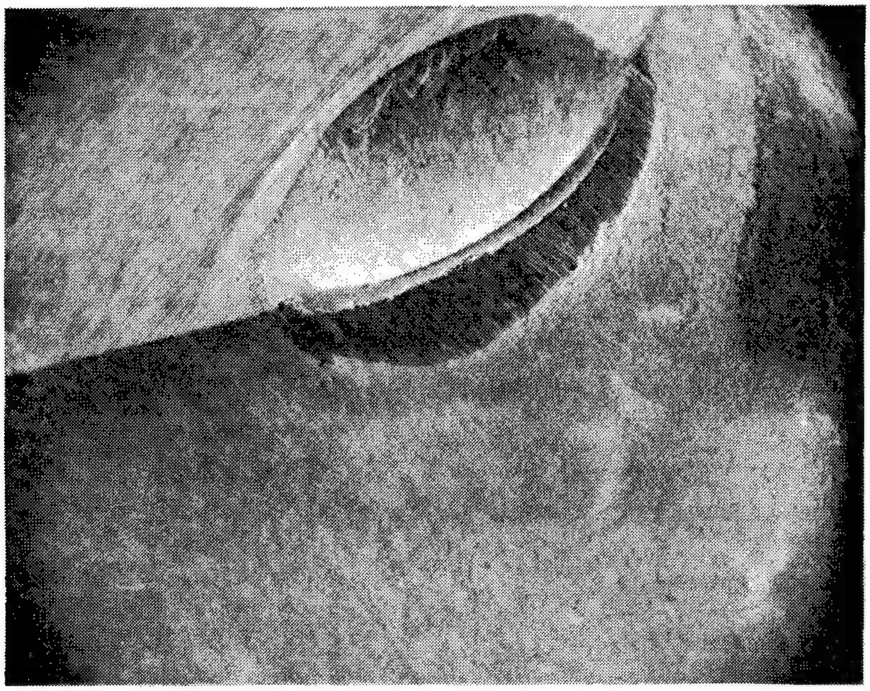
2. Only a slight amount of cooling.

3. An effective wetting agent.

The current cutting fluids used at the Arsenal do not possess all of these properties. This is why chipping is the major mode of milling tool failure.

C. Turning is a temperature sensitive process.

All of the cutting fluids that performed well in the turning tests had one thing in common. They all had properties that would reduce the temperature of the process.



Turning Test Tool 4-A-11; SEM 30X; This Test Used Cincinnati Milacron's Cimcool 400.

Figure 4.3-1. Example of SEM Examination of the Tool Wear Mode for Turning.

D. Approximately 90% of all the water-soluble cutting fluid applications can be filled by two cutting fluids.

Phase II's cutting fluid performance tests indicate that different cutting fluid properties are needed for milling than for turning. Milling requires a cutting fluid that has high lubrication properties with the minimum amount of cooling while turning requires a fluid that has extreme cooling properties. The turning fluid can then be used for grinding.

E. Fluid flow rates affect machining performance.

During the grinding test, a 24% increase in power and as much as a 25% increase in forces were experienced with a slight decrease in fluid flow. Also, in turning a 27% decrease in cubic inches of metal removed to 0.030 inch of flank wear was observed during a test conducted with a slight reduction in fluid flow.

F. Cutting fluid manufacturer's classifications can be misleading.

An important finding of the machining tests was that the cutting fluid manufacturer's ranking system for their cutting fluids, as shown earlier in Table 3.2-1, can be misleading. This is why the Cutting Fluid Application Matrix (Table 3.3-15) was designed to use generic cutting fluid data based on RIA manufacturing operation severity with its own definitive terminology.

G. Eight fluids showed signs of rusting during the fluid evaluation tests.

During the rust test, the following fluids showed signs of rusting: Cimperial 1011, Cincinnati Milacron; IRMCO 103, International Chemical Company; Wheelmate 811, Norton Company; Poly Aqua, Poly-form Oils; 911, Wynn Oil Company; 1149, D. A. Stuart Oil Company; Norsol S090, McGean; and Jon Cool 800; Johnson Wax.

5.0 RECOMMENDATIONS

Based on the Phase I and Phase II program findings, the following immediate and long range preliminary recommendations are presented; these initial recommendations will be further refined in Phase III.

5.1 Immediate Recommendations

The following is a list of suggested courses of action that have the potential to reduce the Rock Island Arsenal's operating cost:

1. Mix the cutting fluids with a positive displacement pump.

   Currently, the cutting fluids are mixed with a Venturi type of mixer. This method's accuracy depends on the variation of the water pressure supplied to it. This may be the major reason that many of the observed sumps have too lean of a cutting fluid mixture.

2. Add bacteria controlling agents to problem machine sumps.

   It was noted that the main reason for cutting fluid discard at RIA was the hydrogen sulfide (rotten egg) odor which can be attributed to a high population of anerobic bacteria. This level is in the range above $1 \times 10^5 \sim 1 \times 10^6$ bacterium on a plate count. Therefore, adding bacteria controlling agents to the cutting fluid will reduce the growth of bacteria and increase the sump's usable life.

3. Mix the make-up cutting fluid to the dilution ratio that is required for the machine operation in question.

   Various machine operations require different dilution ratios for their make-up cutting fluids. The dilution ratios depend on the amount of splashout, the amount of evaporation and/or the amount of dragout of the operation in question. For example, a turning operation is a high dragout operation which is caused by cutting fluid accumulating with the chips. This action removes the diluted cutting fluid mixture from the sump leaving the fluid at the same concentration level. The makeup should be at the recommended concentration level. Grinding produces a high degree of water evaporation from the fluid which increases the concentration of the remaining fluid. This situation calls for a make-up fluid with a lower concentration level which adds more water to the system. This causes the sump concentration level to equalize to the original recommended concentration level.

4. Monitor the concentration levels of all machine sumps.

   Currently, the concentration control of the sumps may be improved if accurate methods to determine their concentration can be developed. A refractometer by itself is not an accurate method to determine the concentration of a cutting fluid after it is in use. The refractometer should be coupled with laboratory tests and used as an indicator that the cutting fluid is within a specified concentration range.

Most cutting fluid manufacturers offer a laboratory service as part of their cutting fluid cost. This service could be used to establish refractometer indices for a particular type of machine with a particular maintenance problem performing a manufacturing process. For example, a group of older lathes could have a hydraulic oil leakage problem. The refractometer index for this group of equipment will be different than if they did not leak hydraulic fluid into the cutting fluid. A refractometer reading should be taken of a sample of the fluid in the machine sump and recorded. Then the same sample should also be sent to the manufacturer's cutting fluid lab for analysis. The actual concentration level of the fluid can then be defined and a calibration factor established for the refractometer readings. Several samples must be taken to develop a refractometer range for this process. When this is determined, accurate make-up cutting fluids can be mixed for this operation. Note: If the cutting fluid ever gets out of the established refractometer range, further lab tests should be made.

Another form of cutting fluid concentration control recommended by some cutting fluid manufacturers is an analytical testing procedure called titration. This procedure measures the exact amount of a critical component of the cutting fluid. This procedure will accurately determine the concentration of the fluid.

Titration cannot be <u>easily</u> performed on all cutting fluids. Each cutting fluid manufacturer being used should be questioned as to how this procedure can best be performed in a manufacturing environment.

5. RIA should institute a machine cleaning program.

Anerobic bacteria is the main reason for cutting fluid sump changes. This form of bacteria will be minimized with an effective machine cleaning program.

6. A study should be made to characterize RIA's material microstructure.

During Phase II's program effort, a definite relationship between microstructure and process machinability was noted. This relationship should be further investigated by the Arsenal.

5.2 Long Range Recommendations

The final recommendations for a cutting fluid system at the Rock Island Arsenal will be made during Phase III of this program. However, the data collected so far at the Arsenal and interfacing with cutting fluid manufacturers have developed some basic thoughts about cutting fluid systems which will be shared in this section.

All of the fluid manufacturers contacted specified the optimal condition of their cutting fluid is when it is applied at the recommended concentration level. The fluid should not have a high bacteria count, over $1 \times 10^5 \sim 1 \times 10^6$ ppm, and should not contain excessive tramp oil contamination.

Observations have indicated that maintaining many individual sumps is an expensive and difficult method of operation. Exact concentration cannot be easily obtained with a refractometer unless monitored on a daily basis. Once tramp oil is in an individual sump, it is difficult to remove unless each individual sump has an oil skimmer or is pumped out and the fluid reprocessed and pumped back in. Having individual oil skimmers is very expensive. Pumping the fluid out and reprocessing is one possible method. However, the concept of a continuous sump is another.

A central sump system would be an integrated cutting fluid system serving a particular group of equipment. An example of the type of equipment serviced would be the N/C equipment in Shop M. The central sump would supply the cutting fluid at the desired operating pressure for a specified group of equipment. The flow of cutting fluid would be set up in such a manner that it would flow through the existing sumps using them like a holding tank. Thus, when central sump equipment failures occur, enough fluid could be kept in the machine's own sump until the equipment is repaired. The central sump's concentration could be easily monitored compared to potential errors involved in individually checking 25-50 smaller sumps. If a synthetic cutting fluid were used, a titration for a required additive could be done which would provide an accurate concentration measurement. Titrating is a chemical analysis method that is used to determine the exact amount of a chemical in a solution. This practice could readily be taught to an hourly employee. Titrations could be run to determine the exact level of biocides and cutting fluid performance additives. Only the desired additives would have to be replenished. The fluid could be reprocessed through a specially designed reprocessing system. However, most cutting fluid manufacturers recommend using medium sized decentralized reprocessing sump systems. They all refer to Murphy's Law and indicate it's better not to put all your eggs in one basket. Also, having more than one system allows for using more than one fluid or fluid concentration. The system sizes will vary depending on the type of fluid used and with what manufacturing process it is utilized. A typical reprocessing system may be viewed in Figure 5.2-1.

This concept is only a basic model at the present time. Examples made were used for illustrative purposes. Additional techniques can be added to this basic concept such as the utilization of automatic feedback control systems. Such systems could be used to test for E.P. additives, bacteria level and amount of rust inhibitor in the system and make additions to the system automatically. Such a system is in the conceptual stages at this point in time and will be further explored during Phase III of the program.

However, it appears at this point in time that a series of centralized systems of some size at particular locations seems to be the optimal solution for the Rock Island Arsenal. The questions that remain to be answered are: What size will they be? How many? Where will they be located? And what cutting fluid and concentration level will they utilize? These questions will be answered after an economic analysis is completed.

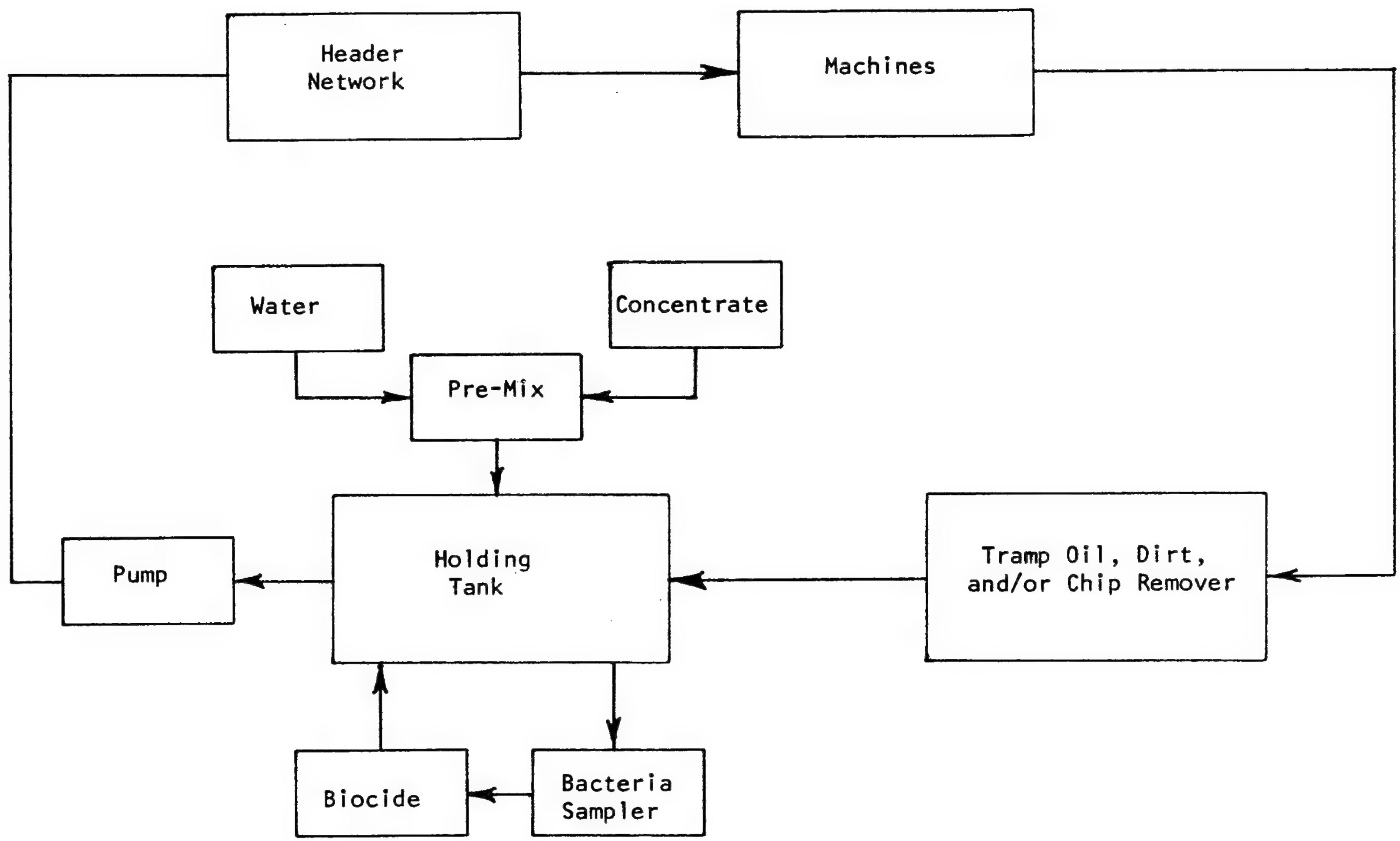


Figure 5.2-1. A Schematic of a Typical Centralized Cutting Fluid System.

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APPENDIX A

Turning Severity Index Determination Table

Weighting Factors Overall Severity Index	3 SFM	1 Depth of Cut (in.)	2 Feed Rate (in/rev)	100 Hardness	6 MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
Ranking Criteria	500-UP=R=3 300-499= R=2 100-299= R=1	0.250-UP=R-3 0.060-0.249= R=2 0-0.059-R=1	0.026-UP= R=3 0.01-0.025= R=2 0-0.009=R=1	41-46=R=2 35-40=R-1 0-34=R=0		200-UP=R=3 50-199=R=2 0-49=R=1			

Key: SFM = Workpiece velocity, surface feet per minute.
Depth of Cut = Tool engagement normal to feed direction, inches.
Feed Rate = Tool advancement rate, inches per revolution.
OTW = Observed tool wear mode.

MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping.
CR = Cratering.
G = Balance between cratering and tool flank wear

Boring Severity Index Determination Table

Weighting Factors	3	1	2	100	17				
Overall Severity Index	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
	Rank=	Rank=	Rank=	Rank=0					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
Ranking Criteria	250-UP=R=3 100-249= R=2 0-99=R=1	0.150-UP=R=3 0.100-0.149 =R=2 0-0.099 =R=1	0.015-UP =R=3 0.012-0.014 =R=2 0.-0.011 =R=1	40-45=R=10 35-40=R=1		100-UP=R=3 50-99=R=2 0-49=R=1			

Key: SFM = Workpiece velocity, surface feet per minute.
Depth of Cut = Tool engagement normal to feed direction, inches.
Feed Rate = Tool advancement rate, inches per revolution.
OTW = Observed tool wear mode.

MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping.
CR = Cratering.
G = Balance between cratering and tool flank wear.

End Milling Severity Index Determination Table

Weighting Factors / Overall Severity Index	3 / SFM	1 / Feed/Tooth (in.)	2 / Feed Rate (in/rev)	200 / Hardness	4 / MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
Ranking Criteria	500-UP=R=3 300-499=R=2 0-299=R=1	0.005-UP=R=3 0.003-0.0049 =R=2 0-0.0029=R=1	7-UP=R=3 3-6.9=R=3 0-2.9=R=1	42-46=R=2 35-41=R=2 0-34=R=0		150-UP=R=3 50-149=R=2 0-49=R=1			

Key: SFM - Tool velocity, surface feet per minute.
Feed per Tooth = Amount of material each tooth removes in inches.
Feed Rate = Tool advancement rate, inches per minute.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.
R = Rank.

Face Milling Severity Index Determination Table

	Overall Severity Index	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
Weighting Factors		3	1	2	200	2				
		Rank=	Rank=	Rank=	Rank=					
		Rank=	Rank=	Rank=	Rank=					
		Rank=	Rank=	Rank=	Rank=					
		Rank=	Rank=	Rank=	Rank=					
		Rank=	Rank=	Rank=	Rank=					
Ranking Criteria		500-UP=R=3 300-499=R=2 0-299=R=1	0.005-UP=R=3 0.003-0.0049 =R=2 0-0.0029=R=1	7-UP=R=3 3-6.9=R=3 0-2.9=R=1	42-46=R=2 35-41=R=2 0-34=R=0		500-UP=R=3 250-499=R=2 0-249=R=1			

Key: SFM = Tool velocity, surface feet per minute.
Feed per Tooth = Amount of material each tooth removes in inches.
Feed Rate = Tool advancement rate, inches per minute.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.
R = Rank.

Conventional Peripheral Milling Severity Index Determination Table

Weighting Factors	3	1	2	200	2				
Overall Severity Index	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
	Rank=	Rank=	Rank=	Rank=					
Ranking Criteria	500-UP=R=3 300-499=R=2 0-299=R=1	0.005-UP=R=3 0.003-0.0049 =R=2 0-0.0029=R=1	7-UP=R=3 3-6.9=R=3 0-2.9=R=1	42-46=R=2 35-41=R=2 0-34=R=0		500-UP=R=3 250-499=R=2 0-249=R=1			

Key: SFM - Tool velocity, surface feet per minute.
Feed per Tooth = Amount of material each tooth removes in inches.
Feed Rate = Tool advancement rate, inches per minute.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.
R = Rank.

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ESTABLISHMENT OF A CUTTING FLUID CONTROL SYSTEM (PHASE II)
by G. A. Lieberman

Report EN-82-08, May 82, 138 p. incl. illus., tables, (AMS Code 3297.06.7948) Unclassified report.

Phase II results are presented for the program entitled "Establishment of a Cutting Fluid Control System." The Phase II objectives were to conduct a systematic evaluation of available cutting fluid products, refine the Phase I preliminary RIA manufacturing process severity index and preliminary cutting fluid application matrix. The study showed the majority of observed machining operations involve milling, turning, grinding and boring procedures on 4100 series steels. A severity index was finalized which ranked all these processes relative to machining difficulty with respect to manufacturing

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Results are presented which indicate fluid performance levels are not necessarily related strictly to overall product formulations and that milling and turning require significantly different fluid properties. Data are also presented which suggest that only a very limited number of fluid types may be required for plant-wide application at Rock Island Arsenal. Methodologies are defined for establishing a quantitative index describing the relative severity of any given metal removal operation in relation to the fluid properties required for optimum performance on the machine. A cutting fluid application matrix is presented describing the generic cutting fluid properties required for the various severity machining operations performed at the Arsenal. Initial recommendations are also presented outlining the design features for a closed-loop fluid reprocessing system.

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